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MODEL TESTS OF THE LOUIS S. ST. LAURENT ORIGINAL BOW FITTED WITH STRAKES

Prepared for

Transportation Development Centre
Transport Canada

by

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July 1988

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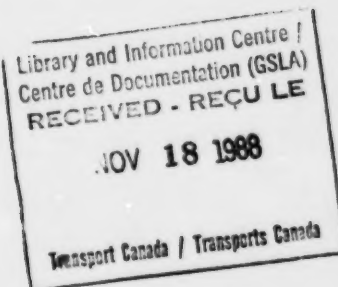
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Montreal, Quebec

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Disclaimer

The contents of this report reflect the views of the Contractor and not necessarily the official views or policies of the Transportation Development Centre.

Un sommaire en français de ce document
est inclus avant la table des matières.

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17. Abstract The concept of using bow strake appendages to deflect the ice down the hull as the ship advances was analytically studied. A sensitivity analysis of the strakes in different positions and orientations was then conducted at the Institute for Marine Dynamics on three simplified bow forms to verify the predictive accuracy of the Carter model under such extremes of contact configurations. Finally, a second model test program was run to perform comparative testing against an existing ship's shape. A 1:15 scale model of the Louis S. St.Laurent was selected for testing as a base for comparison. This report summarizes the findings of the study and compares the results of tests with and without strakes. Fitting the strake appendages to the model hull was found to cause: a) no significant detrimental effect on open water resistance; b) a 25% improvement in icebreaking efficiency			
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17. Résumé Le concept d'utiliser des stries pour enfoncer la glace le long de la coque fut d'abord étudié analytiquement. Ensuite, une étude de sensibilité des stries en différentes positions et orientations fut menée à l'Institut de dynamique marine sur trois formes simplifiées de proue pour vérifier les prédictions du modèle de Carter. Finalement, une seconde série d'essais fut élaborée afin de permettre une évaluation comparative sur une proue de navire existant. C'est le modèle 1 / 15 du Louis S. St.Laurent qui fut retenu comme base de comparaison. Le présent rapport résume les principales conclusions de l'étude et compare les résultats des essais pour les deux situations, avec et sans stries. On peut voir que, lorsque les stries sont attachées à la proue du modèle, il y a : a) Une augmentation imperceptible de la résistance en eau libre; b) Une amélioration significative de 25% de l'efficacité à briser la glace.			
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SUMMARY

Laboratory and field tests have indicated that an ice cover may be much more easily broken in bending by a vertical downward force than in crushing by an in-plane horizontal force. The basic requirement for an efficient icebreaking bow is therefore to transform thrust into vertical forces. This is generally achieved by reducing the stem angle; as a result, ice is quite effectively broken with the forward part of modern icebreaking bows. However, near the aft end of the bow, where the waterline and flare angles are very low, significant detrimental crushing takes place.

It has been suggested by the author that, by fitting strake appendages on the bow shoulder area, the ice will be deflected down the hull as the ship advances, thus producing downward force sufficient to fail the ice in bending. During the first phase of this study, the influence of strake appendages on ice resistance was calculated using the Carter model. The analytical results were promising, showing a potential reduction of 25% in the ice resistance.

In view of the evident economic benefits of enhancing the icebreaking capability of existing ice-going ships, the Transportation Development Centre and the Canadian Coast Guard co-sponsored a model test program designed to verify the predicted influence of the strake appendages.

A series of open water and ice model tests was performed at the Institute for Marine Dynamics on three idealized bow forms fitted with interchangeable panels providing variation in strake geometry. The model test results confirmed the predictive accuracy of the Carter model under such extremes of contact configurations.

Following the sensitivity analysis of the strakes in different positions and orientations, a second model test plan was developed to perform comparative testing against an existing ship's shape. A 1:15 scale model of the Louis S. St. Laurent was selected for testing as a base for comparison. The results of the test program confirmed that using bow strake appendages provides a 25% improvement in icebreaking efficiency, without unduly affecting the open water resistance.

SOMMAIRE

Les essais en laboratoire et in situ montrent qu'il est beaucoup plus facile de briser un champ de glace en flexion vers le bas qu'en compression dans le plan horizontal. L'exigence fondamentale d'une bonne proue brise-glace est donc de pouvoir transformer la poussée en forces verticales. C'est pour atteindre cet objectif qu'on a réduit l'angle d'étrave des récentes proues brise-glaces et, de fait, leur partie avant s'avère très efficace pour briser la glace. Toutefois, près des épaulements, là où les angles au plan d'eau et de dévers sont très petits, on y observe malheureusement de l'écrasement.

L'auteur a suggéré qu'en plaçant des stries sur les épaulements la glace serait ployée le long de la coque, lorsque le navire avancerait, créant ainsi une force suffisante pour briser la glace en flexion. Dans la première phase de l'étude des stries, leur influence sur la résistance de la glace fut calculée à l'aide du modèle numérique de Carter. Les résultats théoriques furent très prometteurs, indiquant une réduction potentielle de 25% de la résistance de la glace.

Les avantages économiques évidents de pouvoir améliorer l'efficacité de navires existants qui opèrent dans les glaces incitèrent le Centre de développement des transports et la Garde côtière canadienne à financer une étude complète sur modèle pour vérifier l'influence prédite des stries.

Une série d'essais en eau libre et dans la glace furent conduites à l'Institut de dynamique marine sur trois formes simplifiées de proue munies de panneaux interchangeables avec des géométries différentes de stries. Les résultats des essais sur modèle confirmèrent les prédictions du modèle Carter pour de telles configurations extrêmes de contact.

Suite à l'analyse de sensibilité des stries dans différentes positions et orientations, un deuxième programme d'essais fut élaboré pour permettre une évaluation comparative sur une forme de navire existant. Le modèle au 1/15 du Louis S. St-Laurent fut retenu comme base de comparaison. Les résultats du programme d'essais confirmèrent que l'emploi de stries pouvait améliorer de 25% l'efficacité dans la glace sans affecter indûment la résistance en eau libre.

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1. INTRODUCTION

It is now well recognized that the fundamental requirement for any low resistance icebreaking bow is to break to the full width of the vessel as much of the ice as possible in bending. However, field observations as well as theoretical analyses indicate that, with most icebreakers, significant crushing takes place near the aft area of the bow, at the shoulders of the vessel, thus reducing the overall icebreaking efficiency.

It has been suggested by the author that, by fitting slightly inclined strakes on the bow shoulder areas, the ice will be deflected down the hull as the ship advances, giving rise to a downward force sufficient to cause ice failure in bending rather than crushing.

This concept was fully developed and theoretically analysed prior to the beginning of the present contract; a request for patent was submitted in May 1986.

In view of the evident economic benefits of enhancing the icebreaking capability of existing vessels by simply welding strakes on their bow shoulder areas, a model study was jointly commissioned by Transportation Development Centre (TDC) and the Canadian Coast Guard (CCG) to verify experimentally the author's analytical predictions.

The objectives of this model testing study were:

- a.: To check the reliability of Carter's math model as a design tool;
- b.: To ascertain the strakes beneficial effects on icebreaking performance and their detrimental effects, if any, on open water resistance.

This program of work was completed in three stages. First, a series of ice tests were carried at the National Research Council Institute for Marine Dynamics (IMD) on three idealized bow forms fitted with interchangeable panels providing variation in strake geometry. From these ice resistance tests, it was possible to isolate the relative influence of all major hull and strake form variables. Details regarding these ice tests may be found in a report entitled: "*Model Tests in Ice of Simplified Forms Fitted with Strakes*". (See Appendix A).

1. INTRODUCTION (Cont'd)

Following this first test program, a comparison between the measured and predicted ice resistance was made in an interim report entitled: *"Icebreaking Resistance of Three Wedge-Shaped Bows Fitted with Strakes"* (Appendix B). Since the ice test results produced a fair correlation with Carter's model predictions, it was then decided to proceed with the third step of the study.

A new icebreaking test program was designed to demonstrate that a substantial improvement in ice performance may be achieved by fitting strakes on the shoulder areas of an existing vessel. The Louis S. St. Laurent 1/15 scale model was selected as a basic hull for this study program. This model has previously been tested both in open water and level ice during the studies commissioned by the CCG for the Louis S. St. Laurent mid-life modernization. It was agreed that these results would be retained to act as a base for comparison of the bow effectiveness with and without strakes. A similar testing program was then carried out at IMD facilities for the model with two strakes fitted on each side of the bow aft end. The test series and final results are presented and discussed in a report entitled: *"Model Tests of the Louis S. St. Laurent Original Bow Fitted with Strakes"* (Appendix C).

This report condenses into a concise presentation the important findings of the three phases of the study. As appendices are given the three above-mentioned reports as well as the computer program developed to evaluate the ice resistance of a bow fitted with strake appendages.

2. BACKGROUND ON ICEBREAKING PROCESSES

From force equilibrium equations, the continuous ice-breaking resistance of ships navigating in level ice is found as the integration, over the entire bow section, of all elementary forces opposing propeller thrust. At any point along the hull, ice forces can be resolved into a normal and a frictional component. The magnitude of these two basic forces depends on both the ice strength and the hull rugosity. However, their direction of action, thence their contribution to ice resistance, is directly linked to the geometry of the hull-ice contact area. For an in-depth analysis of ice forces as a function of the bow form geometry, the reader is referred to Carter [1].

In the forward bow, where both the flare and waterline angles are large, and the buttock angles are low, the downward disruptive force is sufficient to break quite effectively the ice in bending. However, further aft, the waterline and flare angles reduce to very low values and the normal force becomes almost horizontal which results in ice crushing rather than icebreaking.

By fitting strakes on the bow shoulder areas, the geometry of the contact area is modified so that high flare and waterline angles are achieved up to parallel mid-body while, at the same time, keeping buttock angles very low. The definition of the new sets of waterline, flare, and buttock angles corresponding to the "strake-ice" interface is given in Appendix B.

Two design constraints were imposed on the final choice of the strake configuration:

- 1.: The configuration would have to be suitable for easy building and welding on the hull of existing ships;
- 2.: The configuration would have to significantly improve the bow icebreaking capability without unduly affecting its open water resistance.

Within this framework, it was decided, in consultations with TDC, to test triangular strakes with equal sides of 30 cm (12 inches) in full scale. The strake position shown in Figure 2.1, was based upon calculations made with the program given as Appendix D. The calculated percent improvement in ice resistance is shown in Figure 2.2. Since no significant benefits are achieved above two strakes, it was decided not to test more than two strakes because the detrimental effect this may have on the open water resistance.

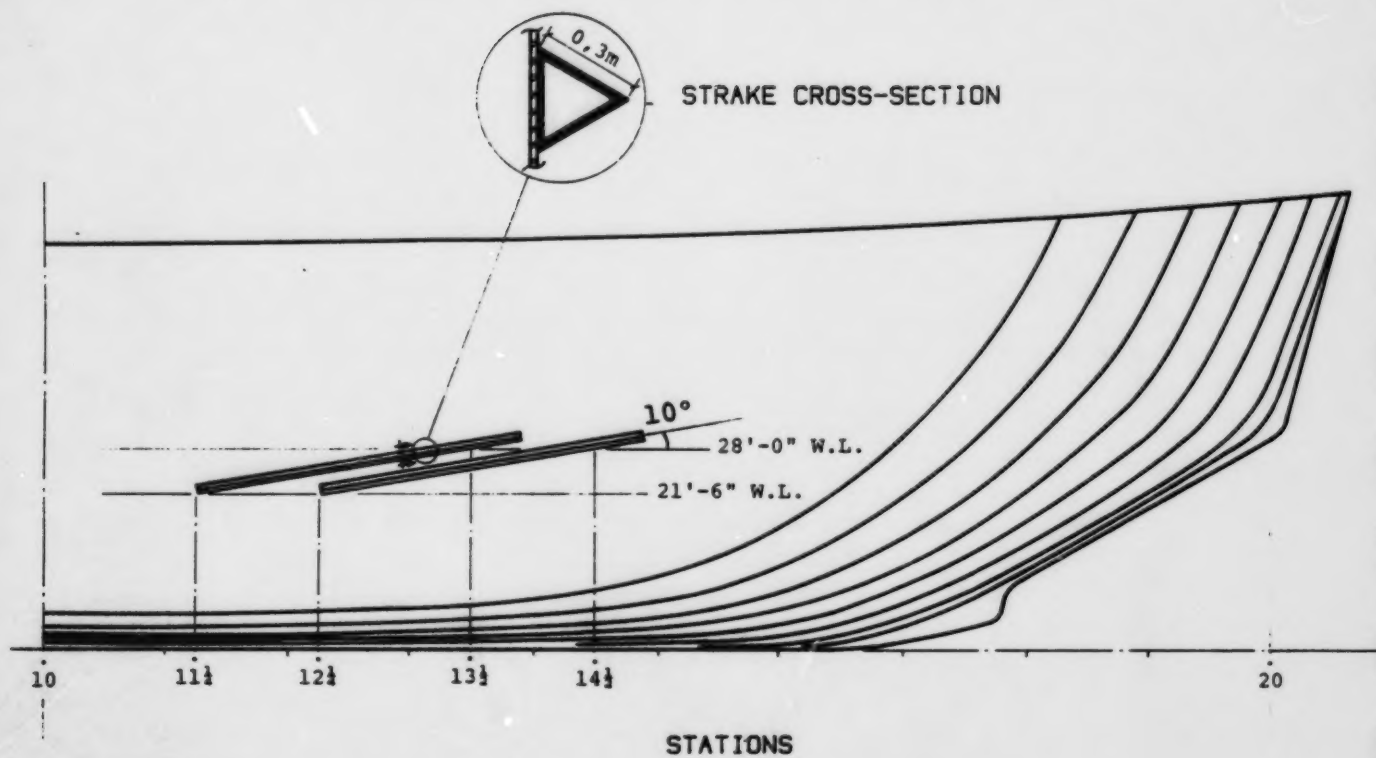
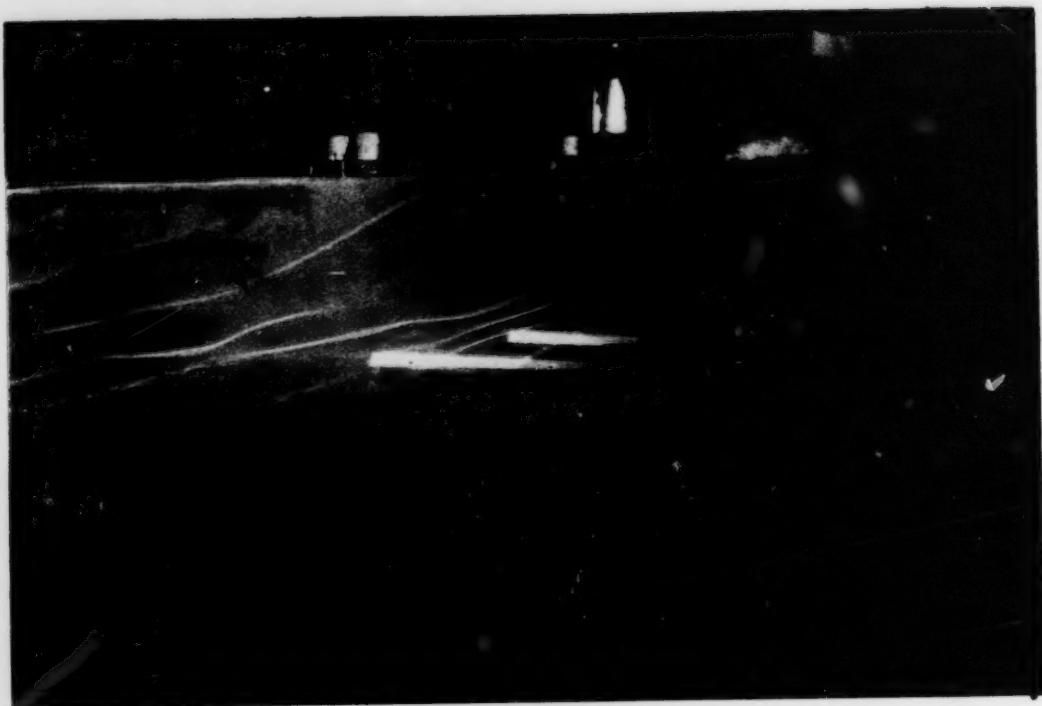
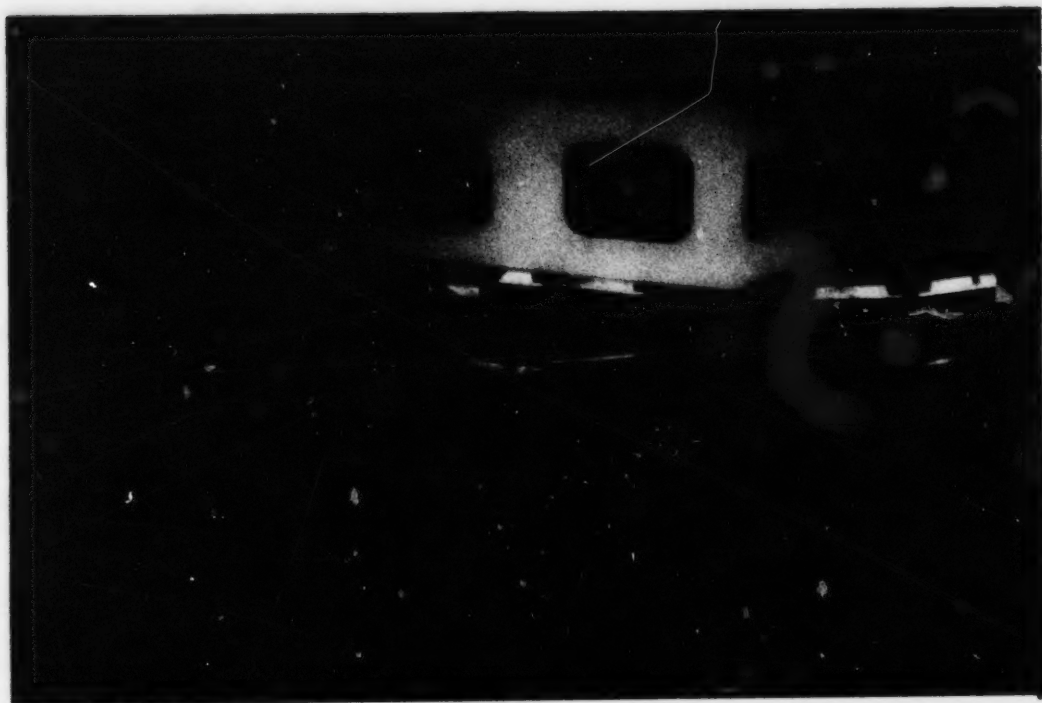


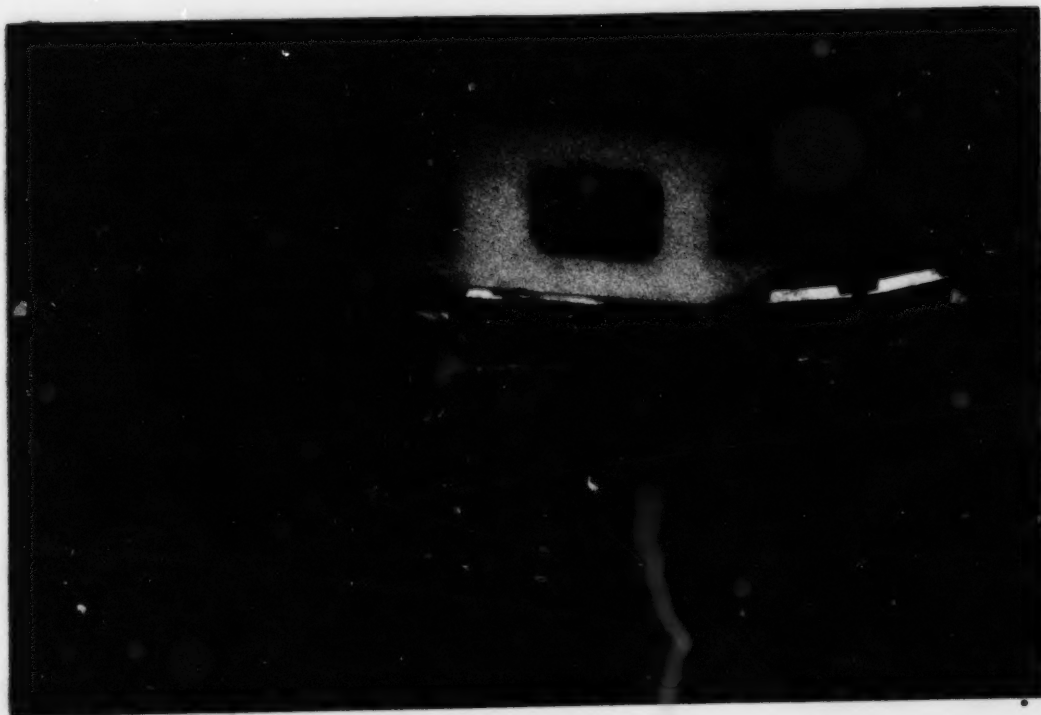
FIGURE 2.1: STRAKE POSITION ON THE BOW SHOULDER AREA
OF THE LOUIS S. ST. LAURENT



Photos 1 & 2.: Strake Appendages on the 1/15 model of the
Louis S. St.Laurent original bow.



At 0,500 m Draft (24,6 ft Full Scale)



At 0,587 m Draft (27,8 ft Full Scale)

Photos 3 & 4.: Cusp formation, due to bending, along the bow shoulder areas fitted with the strake appendages.

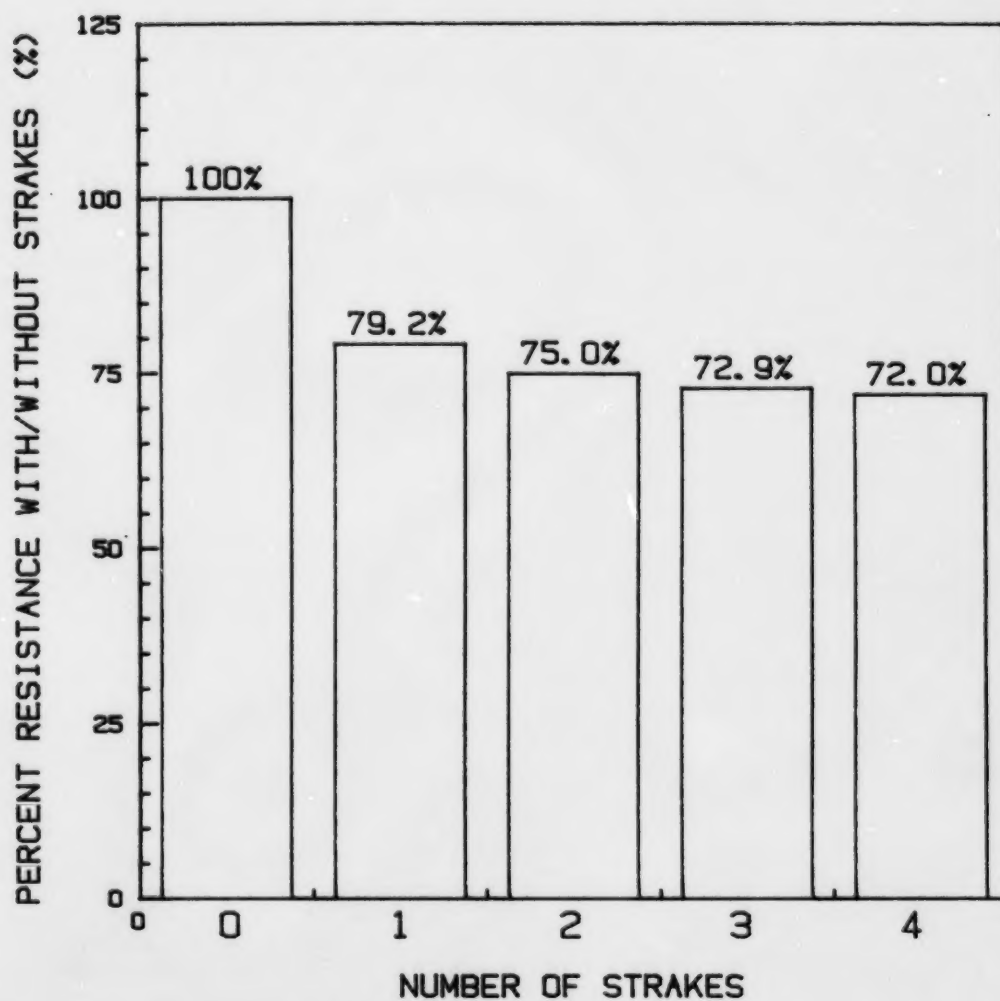


FIGURE 2.2: PERCENT ICE RESISTANCE WITH/WITHOUT STRAKES VS. NUMBER OF STRAKES ON EACH SIDE OF FOREBODY SECTION FOR THE ORIGINAL LUIS S. ST. LAURENT HULL.

3. MODEL TEST RESULTS

In order to properly assess the predicted strake beneficial effect on icebreaking performance and the potential detrimental effect on open water resistance, a series of open water and ice tank tests was carried out at IMD with an existing 1/15 model of the original St.Laurent bow fitted "with" strakes.

The results obtained, for the same model "without" strakes, in a testing program commissioned by the Canadian Coast Guard [2] were retained to act as a base for comparison.

3.1.: Open Water Tests

The open water resistance tests were conducted over the speed range 0 to 2,5 m/s (0 to 20 knots) using standard model test practices. The test program is presented in Appendix C and in reference [3]. These documents should be referred to for detailed analysis and interpretation.

Figure 3.1 shows the results of the open water resistance tests for the 1/15 model of the original St.Laurent "with" and "without" strakes. It can be seen in this figure that, because the two curves are so close together, there is, in terms of model test accuracy, no significant effect on open water resistance due to fitting two pairs of strakes on the model.

TABLE 3.1

OPEN WATER RESISTANCE TEST RESULTS

MODEL SPEED (m/s)	1/15 MODEL OF THE ST.LAURENT ORIGINAL BOW Open Water Resistance (Newtons)		
	WITHOUT STRAKES	WITH STRAKES	
		Draft = 8,5 m	Draft = 7,5 m
0,50	8	8	7
0,75	17	17	17
1,00	27	30	27
1,25	45	48	45
1,50	66	67	66
1,75	92	98	92
2,00	135	146	140
2,25	200	218	207
2,50	370	400	370

MODEL OF LOUIS S. ST. LAURENT ORIGINAL BOW

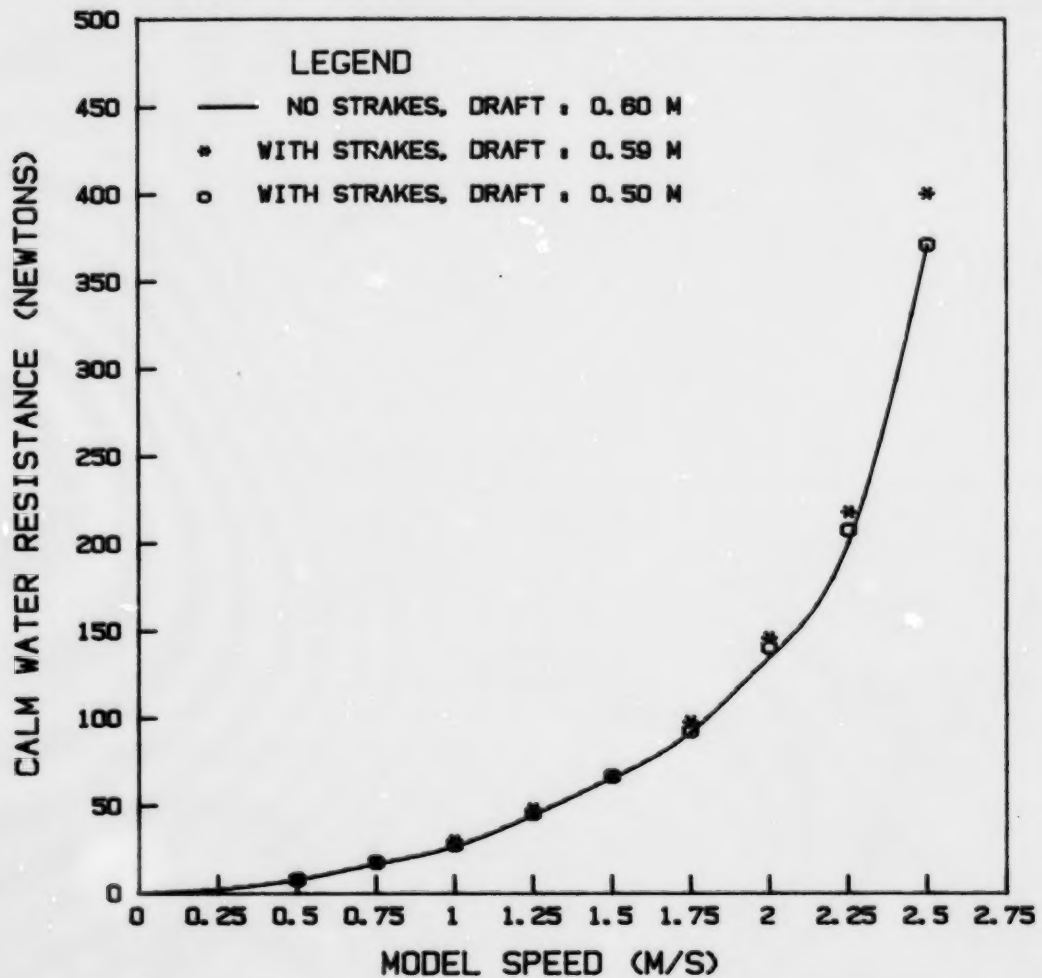


FIGURE 3.1: CALM WATER RESISTANCE WITH AND WITHOUT STRAKES
(reproduced from Appendix "C")

3. MODEL TEST RESULTS (Cont'd)

3.2.: Ice Tests

In order to allow an easy comparison with the base data points, similar test conditions were retained for the icebreaking resistance tests of the Louis S. St.Laurent model fitted with two strakes.

	Model Scale	Full Scale
Ice thickness	66,7 mm	1,0 m
Speed	0,258 and 0,774 m/s	1,94 and 5,81 knots
Ice strength	30 kPa	450 kPa
Friction Coef.	0,1	0,1
Draft	0,57 and 0,5 m	8,5 and 7,5 m

The model test results for both situations, with and without strakes, are shown in Figure 3.2 along with the math predictions obtained by the use of Carter's model. It can be seen from this figure that:

- 1.: a 25% improvement in ice performance is observed for the model with strakes;
- 2.: a remarkable agreement is observed between the ice resistance measurements and predictions by Carter's math model.

TABLE 3.2
LEVEL ICE TEST RESULTS

MODEL SPEED (m/s)	1/15 MODEL OF THE ST.LAURENT ORIGINAL BOW Level Ice Resistance (Newtons)		
	WITHOUT STRAKES, R ₁	WITH STRAKES, R ₂	RATIO R ₂ / R ₁
0,258	601	445*	74,0%
0,774	836	598*	71,5%
0,258	601	449°	74,7%
0,774	836	630°	75,4%

* Draft = 0,50 m

° Draft = 0,57 m

ICE RESISTANCE PREDICTIONS BY CARTER'S MODEL

0,000	569	427	75,0%
0,258	605	456	75,0%
0,516	702	526	75,0%
0,774	838	629	75,0%

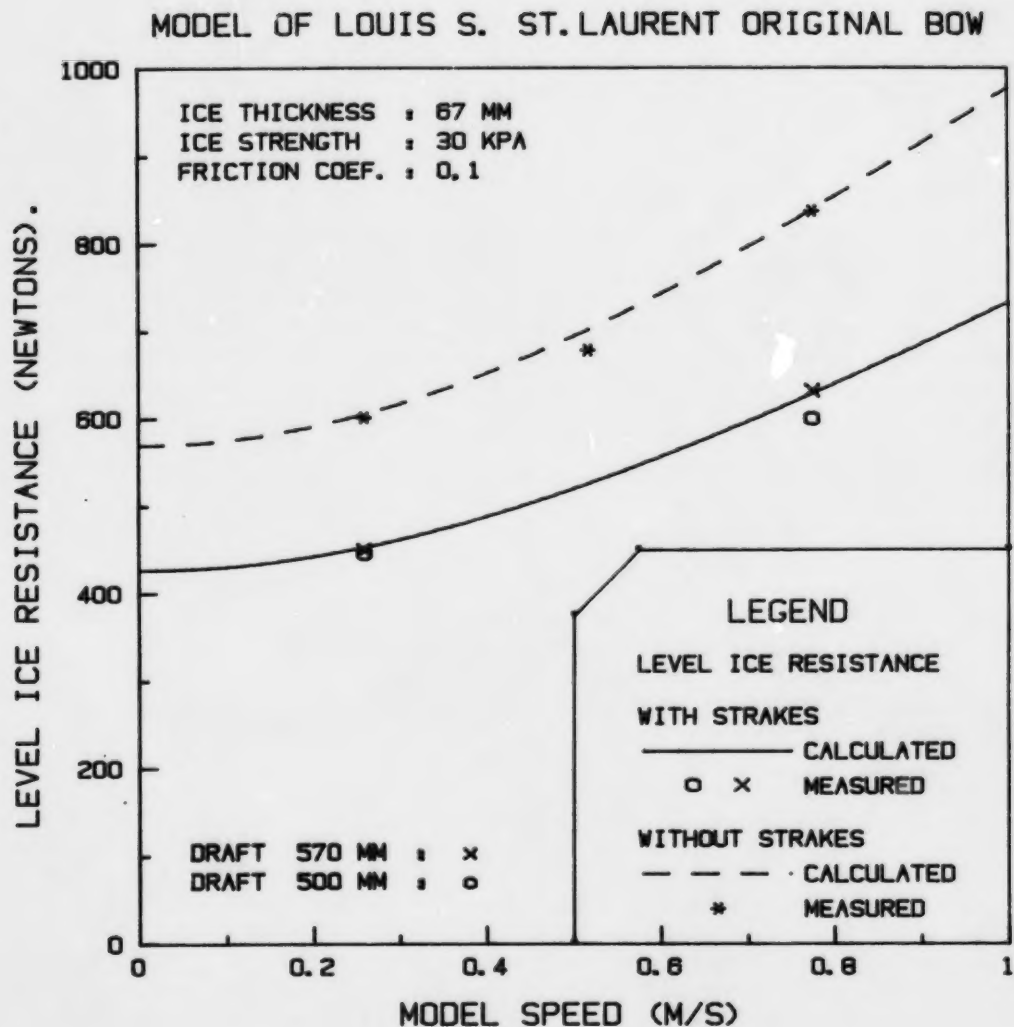


FIGURE 3.2: LEVEL ICE RESISTANCE WITH AND WITHOUT STRAKES.
MATHEMATICAL PREDICTION AND MODEL TEST RESULTS.

4. CONCLUSIONS

The objective of this study was to verify the applicability of the Carter's math model and the strakes beneficial effects on icebreaking. Based on the results of the testing program, the following main conclusions may be made:

- 1.: The ice test results are in good agreement with the mathematical predictions both for the idealized bow forms and the actual St.Laurent bow with and without strakes. Such extremes of ice contact configurations have severely tested the flexibility, adaptability, and predictive accuracy of the Carter's analytical model.
- 2.: The open water test results indicated no significant detrimental effect due to attaching two (2) pairs of strakes on the forebody section of the original St.Laurent bow.
- 3.: Compared to the St.Laurent original bow with no strakes, a substantial 25% improvement in icebreaking efficiency has been achieved by simply fitting two (2) pairs of strakes on the bow shoulder areas.

Generally the whole testing program of the strake concept can be considered a success. A better icebreaking performance of the Louis S. St.Laurent has been achieved without unduly affecting its open water resistance. The strakes have proven to be very efficient and inexpensive means to improve icebreaking capability while, at the same time, strengthening the bow section where most ice damages occur.

On the basis of the model test results, it seems justified to recommend a demonstration program to implement the technology flowing from the present research program.

5. REFERENCES

- [1] Carter, D. 1987, Mathematical Model for Predicting Icebreaking Performance. Report prepared for Transportation Development Centre, TP 8531E, June 1987, 102 pages.
- [2] Spencer, D. 1987, Ice Model Tests on CCGS LOUIS S. ST.LAURENT - Phase 1 - National Research Council of Canada Institute for Marine Dynamics, TR-AVR-01 19 pages plus figures
- [3] Molyneux, W.D. and Simoés Ré, A.J. 1987, Louis S. St.Laurent: Results of Experiments with Models 395A, 395B, and 395C in Calm Water and Irregular Head Waves. National Research Council of Canada Institute for Marine Dynamics, TR-HYD-07, 9 pages, 51 Figures, and 63 Tables.

APPENDIX "A"

IMD First Report

Simplified Forms Fitted with Strakes.

LIMITED

MODEL TESTS IN ICE OF SIMPLIFIED FORMS
FITTED WITH STRAKES
FINAL REPORT

TR-AVR-06

B. Colbourne

April 1987

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KEY WORDS: model test, icebreaking, strakes		PAGES 6	FIGS. 10	TABLES -
SUMMARY: A series of model tests in ice was performed on simplified hull shapes fitted with closely spaced strakes on the sides of the bow. The models varied bow angles, strake size and depth of strake immersion and were fully restrained in all modes of motion. The results indicate that for some configurations the strakes caused an increase in ice resistance while for other configurations they decreased the ice resistance.				
ADDRESS National Research Council Institute for Marine Dynamics P.O. Box 12093 St. John's, Newfoundland A1B 3J5 (709) 772-2326				

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MODEL TESTS IN ICE OF SIMPLIFIED FORMS FITTED WITH STRAKES

1.0 INTRODUCTION

This report details a series of model tests carried out in the IMD Ice Tank on behalf of Dr. Donald Carter, Consulting Engineer. The purpose of these tests was to demonstrate the effect of fitting "strakes" on the bow shoulder areas of icebreaking vessels. Because the tests were very preliminary in nature, highly simplified models were employed.

Testing was conducted in the period February 16 to February 19, 1987 and April 1 to April 3, 1987 and consisted of open water runs and tests in ice of a single thickness. Three models were tested providing variation in bow angles and each model was fitted with interchangeable panels for testing with and without strakes. The draft of the models was varied to provide differing degrees of strake immersion. In all cases, the models were fully restrained in all degrees of motion.

In general the test results indicated that for the deeper drafts (more strake immersion) the strake configurations increased the ice resistance of the models, while at shallower drafts (less strake immersion) the strakes reduced the ice resistance.

2.0 MODELS

The models were of plywood construction and designated Carter Models A, B and C. These models were supplied by Dr. Carter for the purposes of this test series. Diagrams are shown in Figures 1 through 3. The forward sections of each model had removable panels, which could be replaced with strakes to allow direct comparison with and without strakes. Models A and C were tested without strakes and with 2 cm. strakes while model B was tested without strakes and with 1, 2 and 3 cm. strakes. A diagram of typical strake panel is given in Figure 4.

The models were designated A0, A2, B0, B1, B2, B3, C1, C2 to give 8 different configurations. In each case the letter indicates the model and the number indicates the strake size in cm.

3.0 EXPERIMENTAL ARRANGEMENT

Models were restrained in all degrees of motion using a measurement frame suspended on 4 sets of linear roller bearings. The tow force on the frame was measured with a 100 lb. S type load cell pretensioned with a 15 kg weight. A schematic of this

arrangement is shown in Figure 5. In addition to tow force, the carriage speed was measured and recorded, and video records were kept of all tests.

It should be noted that some problems were experienced in aligning the measurement frame support bearings. The use of eight support points provided excessive redundancy leading to problems with binding. These problems were resolved by reducing the number of support points to four but did result in one bad run. It is suggested for future model tests requiring this type of motion restraint that non-redundant support systems be used and that special attention be paid to the need for alignment.

A slight stickiness in the bearings resulted in a measurement error for the system of about 3 to 4 Newtons. This error only became significant for the open water runs where small loads were experienced.

Tests were conducted at model drafts of 175mm and 100mm. In addition the A2 model was tested at 125mm and 150mm. Because the interest is in the effect of strake immersion these drafts are translated to strake drafts to give an indication of the effective depth of the strakes on the side of the model. The strake draft is the vertical distance from the bottom of the strakes to the waterline.

Prior to each test a 100 mm wide channel was sawn in the ice to remove the stem icebreaking component. This was done to better isolate the icebreaking effect at the sides of the bow where the strakes were located. The length of runs in ice ranged from 10 to 15 m or 4 to 6 model lengths. Data was collected for the entire length of the test and analysed over the period where a reasonable steady state condition was apparent. The ice resistance was taken as the mean tow force over this steady state period.

Frictional coefficients at various normal loads were measured on Model B0 resulting in a mean ice-model friction coefficient of about 0.5. Results are shown in Fig. 10.

4.0 RESULTS

The open water results for the models are given in the following table (Resistances in Newtons): Model Draft = 175mm
Strake Draft = 105mm

Model	.15 m/s	.50 m/s	.85 m/s
A0	.68	4.80	12.77
A2	1.94	6.11	14.15
B0	1.72	6.18	12.41
C0	1.13	5.90	12.83
C2	2.02	6.78	13.76

Testing of the B series models in open water was not completed because of problems with the measurement frame and because the models did not exhibit differences greater than the measurement error inherent in the test frame.

Resistance results at .15 m/s in ice are given in the following table including mean resistance, and standard deviation. These values have not had open water resistances subtracted.

Model	Strake Draft (mm)	Ice Thk. (mm)	Ice Str. (kPa)	Mean Res (N)	Standard Dev (N)
A0	105	27	32	77.5	23.1
A0	30	29	35	127.8	57.1
A2	105	27	30	133.4	38.6
A2	80	29	34	145.1	54.6
A2	55	29	33	135.3	71.0
A2	30	29	34	97.9	33.4
B0	105	28	22	26.8	11.3
B0	30	30	35	74.4	38.8
B1	105	28	19	103.1	31.0
B1	30	30	42	52.6	34.3
B2	105	28	20	129.6	35.4
B2	30	30	40	53.6	31.2
B3	105	28	21	144.5	41.6
B3	30	30	38	59.1	47.0
C0	105	27	27	19.3	6.4
C0	30	29	33	26.8	15.6
C2	105	27	28	137.3	44.6
C2	30	29	32	37.3	19.2

Examples of the resistance traces are shown in Figures 8 and 9.

5.0 DISCUSSION

Results of the tests show that for deeper drafts the strakes greatly increased the ice resistance of the models. The increase came about because the strakes prevented the ice sheet from deflecting down the hull as the model advanced. This resulted in high in-plane forces in the ice which eventually

caused failure in buckling. The situation was probably slightly compounded by the fact that the models were restrained in pitch and heave.

At shallower drafts, the strakes were only immersed to the depth of the ice. As the ice sheet was depressed by the first strake it did not suffer interference from the strake below and was able to deflect down the smooth part of the hull thus giving rise to lower resistance. This trend was evident for models A and B but not model C. Model C showed higher resistance with strakes even at the shallow draft.

The test results suggest that there is probably an interaction between bow flare angle, forward speed and strake angle. It seems likely that strakes would be beneficial in reducing ice resistance when they assist the ice in following a smooth path down along the hull sides. In cases where the strakes interfere with this path they act to increase the resistance.

With regard to strake size, larger strakes tend to increase the ice resistance although this trend was not as pronounced at the shallow draft. (See Fig. 7).

6.0 ICE PROPERTIES

Ice properties are presented for each of the four ice sheets used in the test series. Because ice properties change in time and the tests in each sheet extended over an hour, the flexural strength is interpolated and estimated for each test. Other properties are reported as averages of the values recorded before the tests and those recorded immediately after, or the time of recording is indicated.

Sheet 1 February 16, 1987

Flexural Strength	Test	Time
32 kPa	A0(105)	1147
30 kPa	A2(105)	1205
28 kPa	C2(105)	1218
27 kPa	C0(105)	1234

Elastic Modulus Recorded at 1345
E = 12.4 MPa
 σ = 19 kPa (extrapolated)
E/ σ = 650

Ice Thickness
Mean Ice Thickness = 27 mm

Fracture Toughness
 K_{Ic} = 5.1 Recorded at 1110

Compressive Strength

 $\sigma_{cm} = 51.5 \text{ kPa}$ Recorded at 1250

Ice Density

 $\rho = .945 \text{ Mg/m}^3$ Recorded at 1420Sheet 2 February 17, 1987

Flexural Strength

	Test	Time
22 kPa	B0(105)	1203
21 kPa	B3(105)	1216
20 kPa	B2(105)	1229
19 kPa	B1(105)	1242

Elastic Modulus Recorded at 1020

 $E = 37.1 \text{ MPa}$ $\sigma = 32 \text{ kPa}$ $E/\sigma = 1160$

Ice Thickness

Mean Ice Thickness = 28.3 mm.

Fracture Toughness

 $K_{Ic} = 3.8$ Recorded at 1250

Compressive Strength

 $\sigma_{cm} = 49.5 \text{ kPa}$ Recorded at 1330

Ice Density

 $\rho = .947 \text{ Mg/m}^3$ Recorded at 1330Sheet 3 April 2, 1987

Flexural Strength

	Test	Time
42 kPa	B1(30)	1301
40 kPa	B2(30)	1316
38 kPa	B3(30)	1332
35 kPa	B0(30)	1354

Elastic Modulus Recorded at 1205

 $E = 62 \text{ MPa}$ $\sigma = 48 \text{ kPa}$ (extrapolated) $E/\sigma = 1290$

Ice Thickness

Mean Ice Thickness 29.9 mm

Fracture Toughness

Not Recorded

Compressive Strength

 $\sigma_{cm} = 88 \text{ kPa}$ Recorded at 1250

Ice Density

 $\rho = .946 \text{ Mg/m}^3$ Recorded at 1415Sheet 4 Arpil 3, 1987

Flexural Strength

	Test	Time
35 kPa	A0(30)	1118
34 kPa	A2(30)	1136
34 kPa	A2(80)	1143
33 kPa	A2(55)	1149
33 kPa	C0(30)	1203
32 kPa	C2(30)	1217

Elastic Modulus Recorded at 0945

 $E = 58 \text{ MPa}$ $\sigma = 49 \text{ kPa}$ (extrapolated) $E/\sigma = 1180$

Ice Thickness

Mean Ice Thickness = 28.9 mm

Fracture Toughness

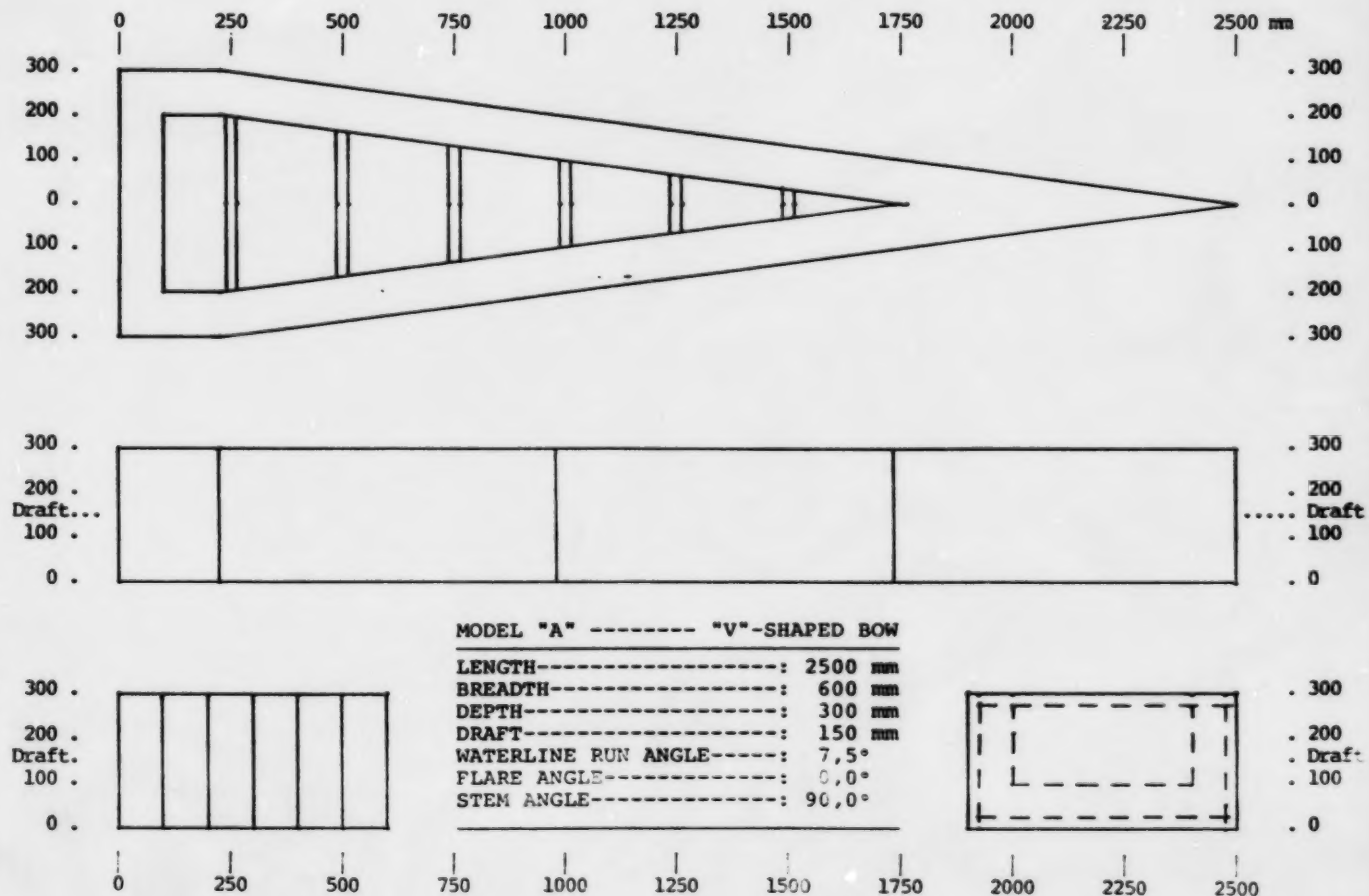
Not Recorded

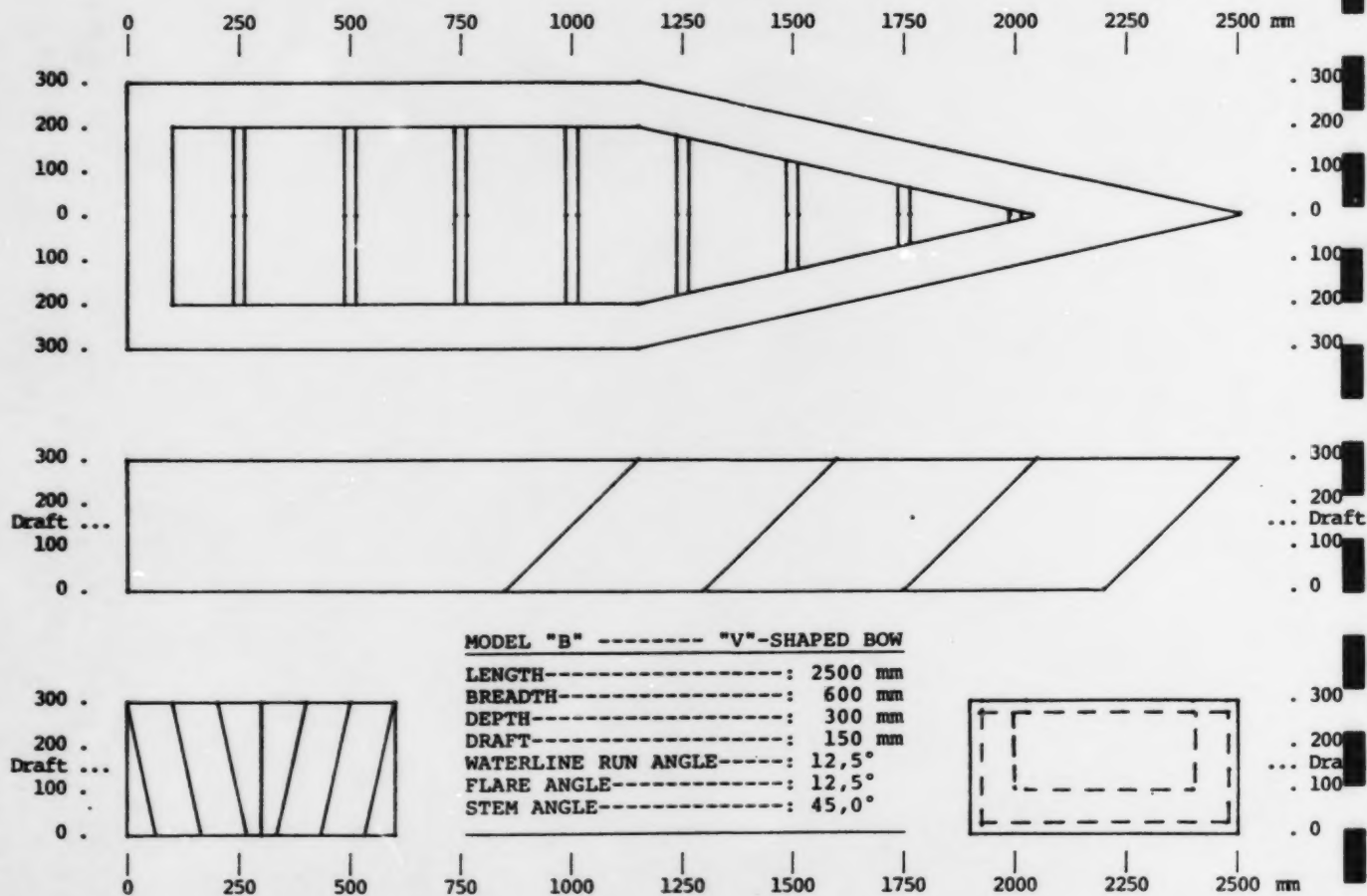
Compressive Strength

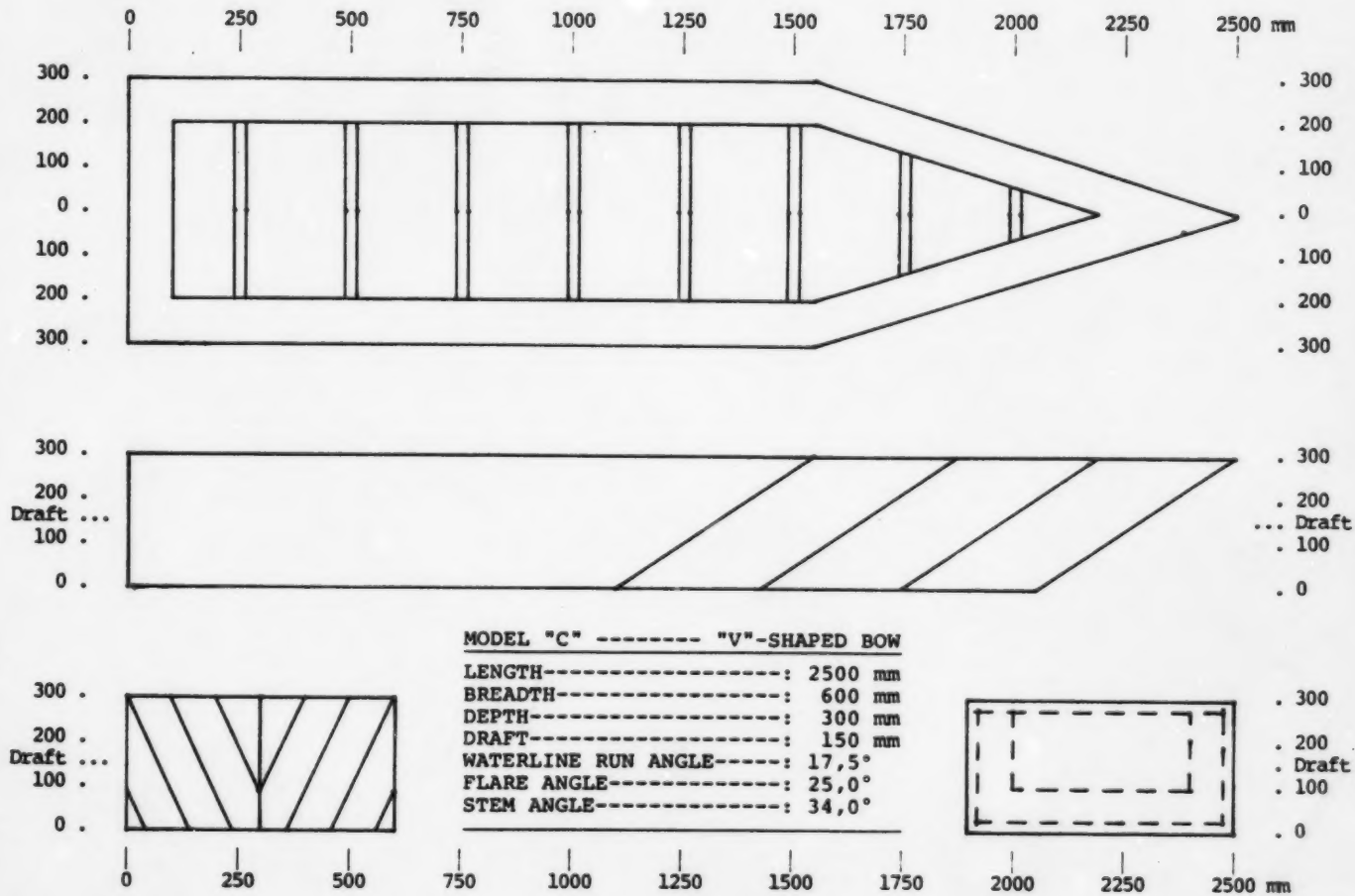
 $\sigma_{cm} = 100 \text{ kPa}$ Recorded at 1000

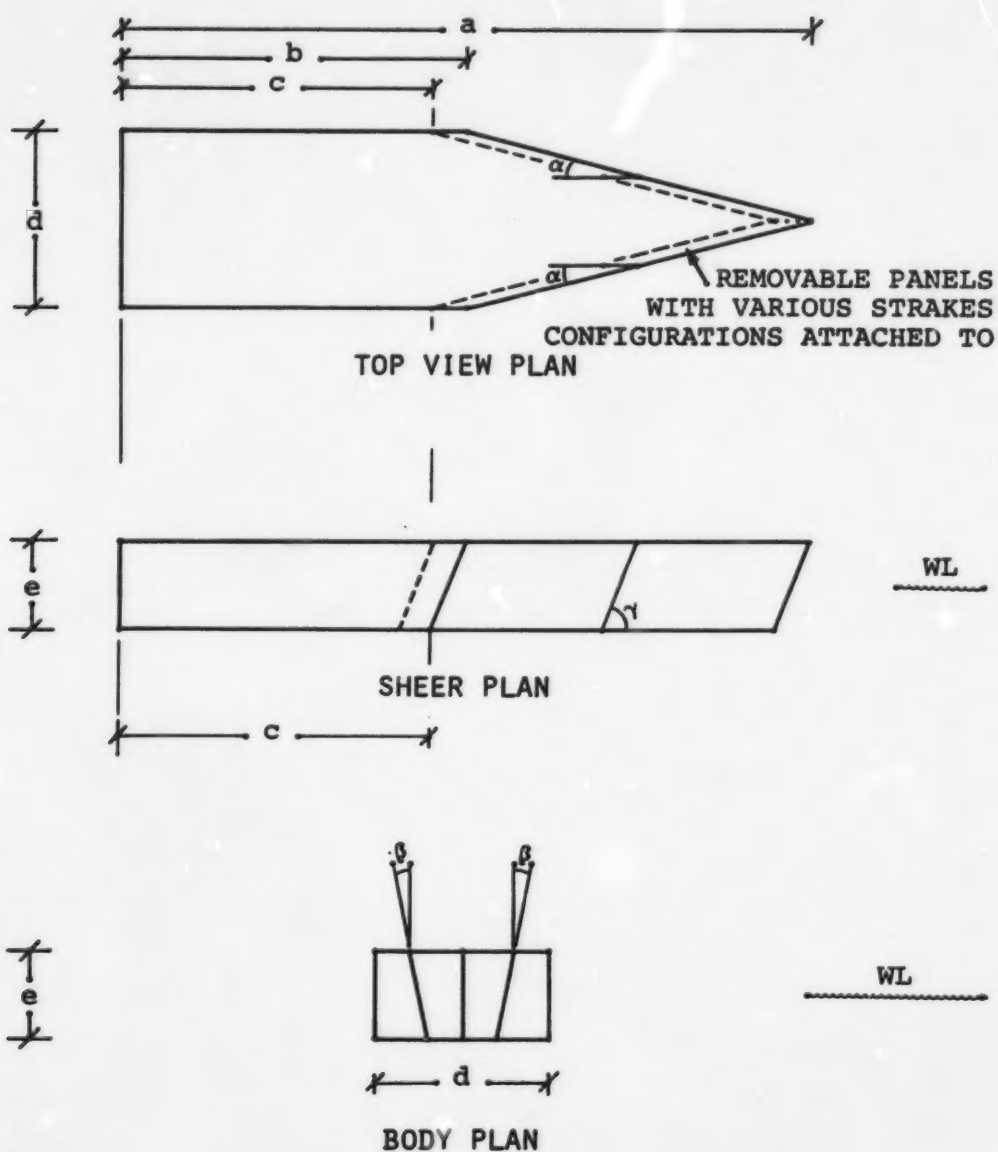
Ice Density

 $\rho = .944 \text{ Mg/m}^3$ Recorded at 1240

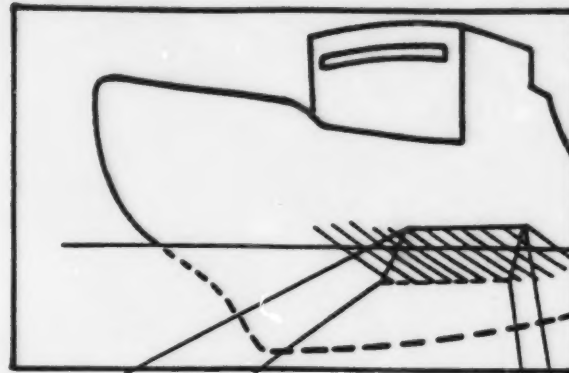








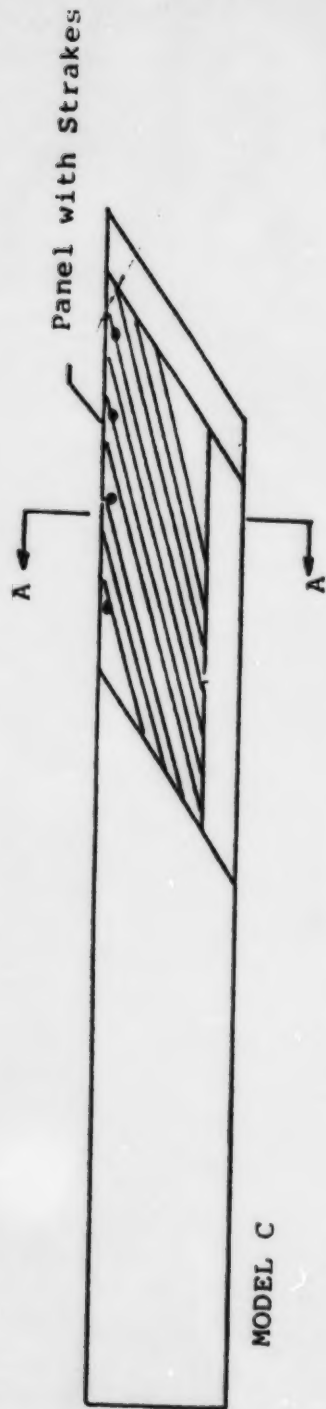
MODEL NAME	GEOMETRICAL CHARACTERISTICS							
	a (mm)	b (mm)	c (mm)	d (mm)	e (mm)	α (°)	β (°)	γ (°)
MODEL A	3280	1000	1000	600	250	7,5	0,0	90,0
MODEL B	2709	1356	1106	600	250	12,5	12,5	45,0
MODEL C	2468	1517	1147	600	250	17,5	25,0	34,0



PRINCIPAL PARTICULARS OF MODELS

MODEL	MODEL PARTICULARS					"STRAKES"	
	LENGTH (mm)	WIDTH (mm)	DRAFT (mm)	SPREAD ANGLE	FLARE ANGLE	SLOPE ANGLE	SIZE (mm)
MODEL "A" + PANELS "A0"	2500	600	125	7,5	0,0	-	NUL*
MODEL "A" + PANELS "A2"	" "	" "	" "	" "	" "	10	12
MODEL "B" + PANELS "B0"	2500	600	125	12,5	12,5	-	NUL
MODEL "B" + PANELS "B1"	" "	" "	" "	" "	" "	15	6
MODEL "B" + PANELS "B2"	" "	" "	" "	" "	" "	15	12
MODEL "B" + PANELS "B3"	" "	" "	" "	" "	" "	15	19
MODEL "C" + PANELS "C0"	2500	600	125	17,5	25,0	-	NUL
MODEL "C" + PANELS "C2"	" "	" "	" "	" "	" "	20	12

* : Without strakes.



MODEL C

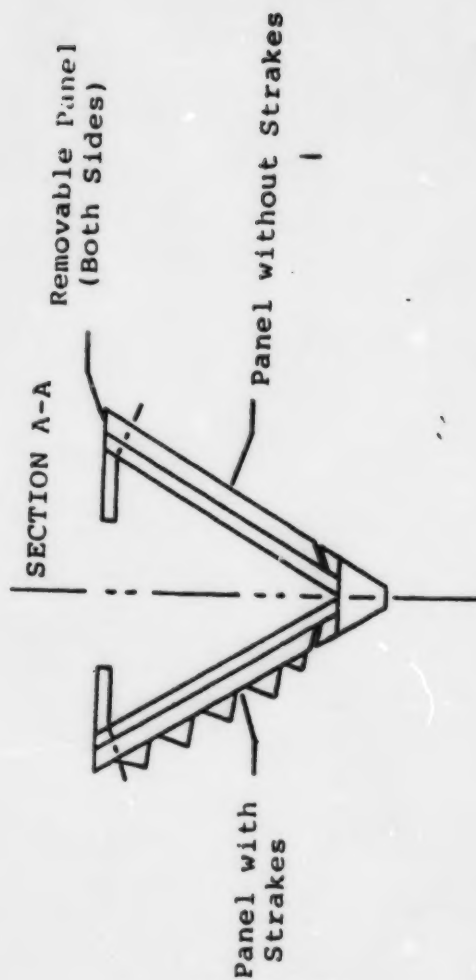


Figure 4 Strake Panel

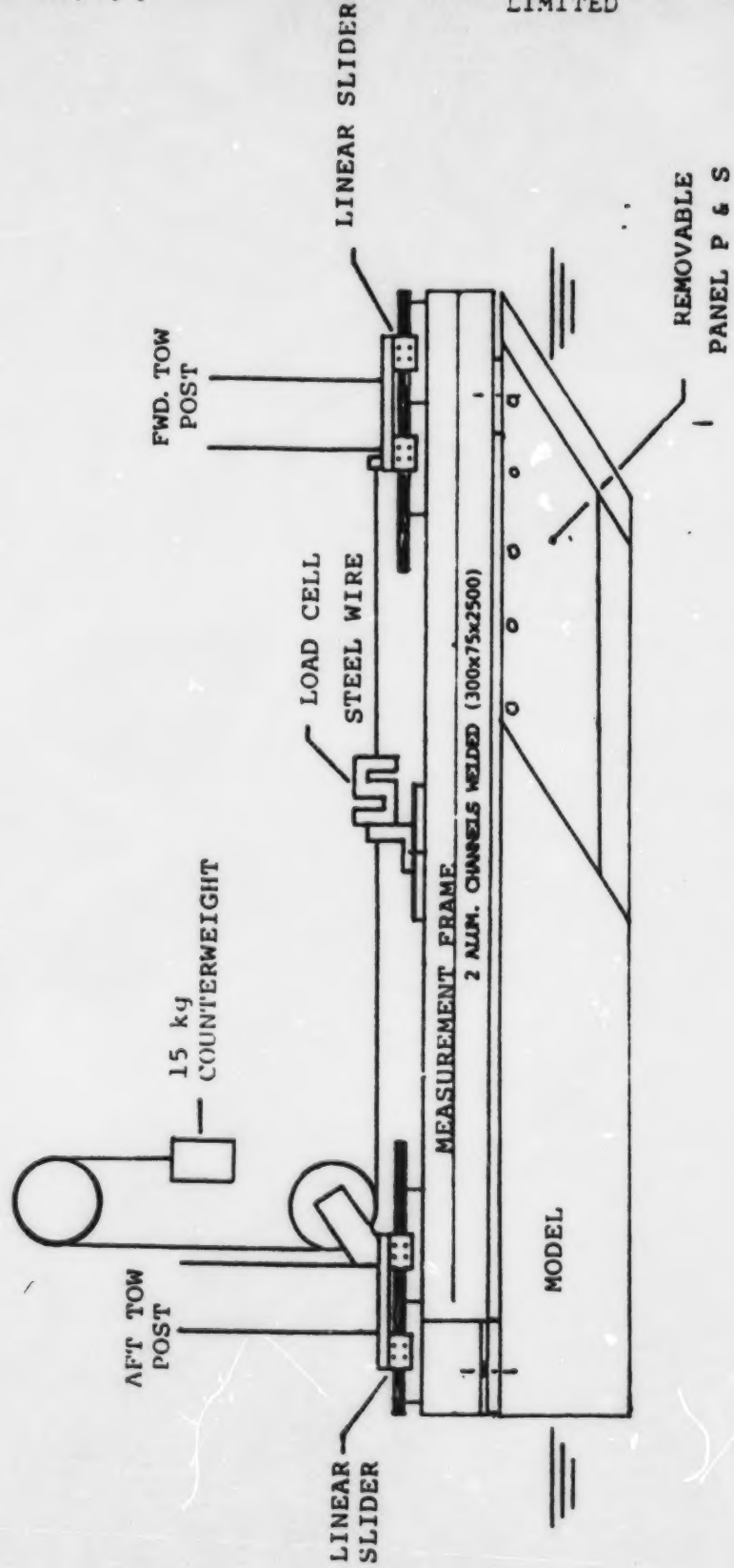
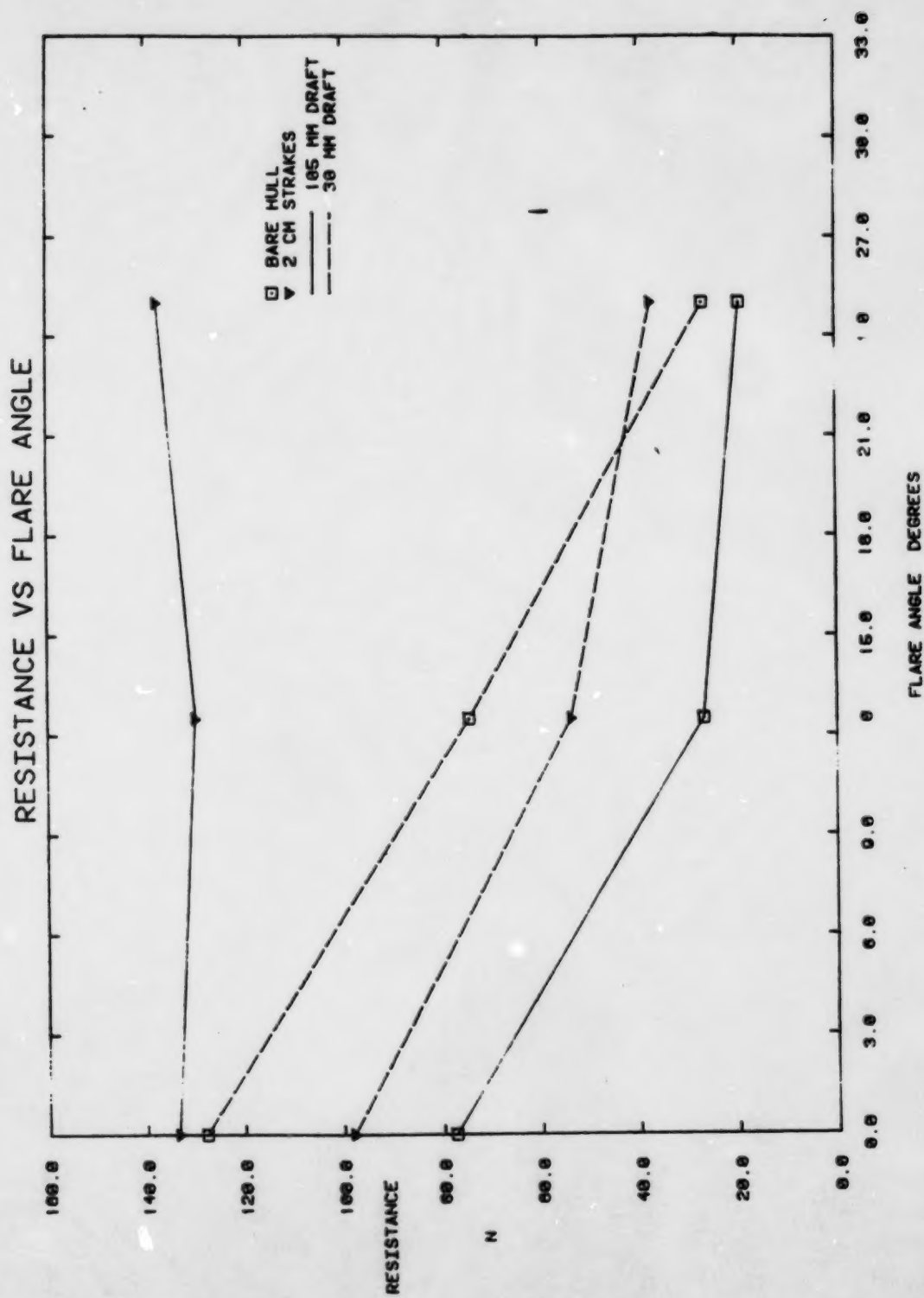
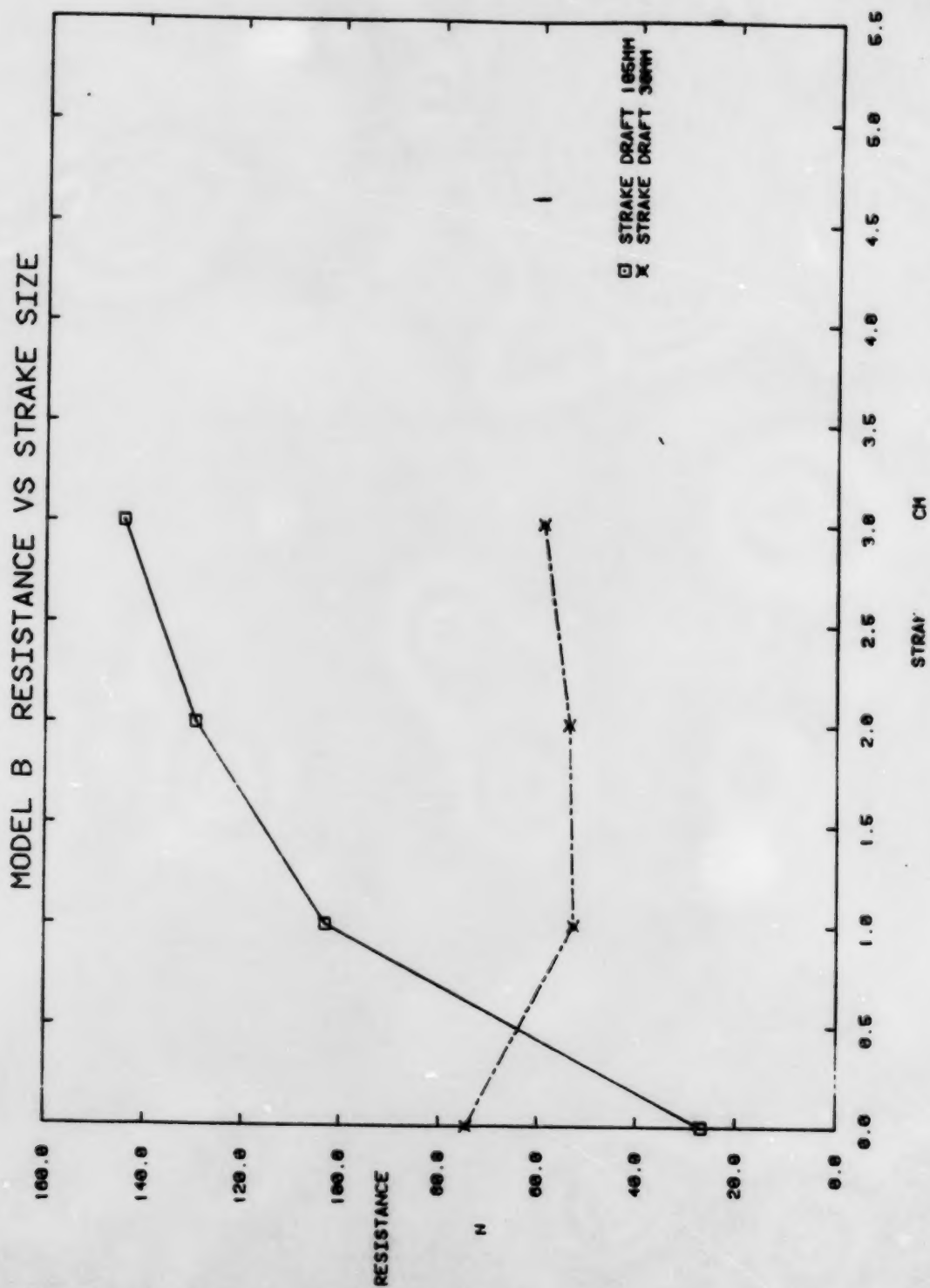
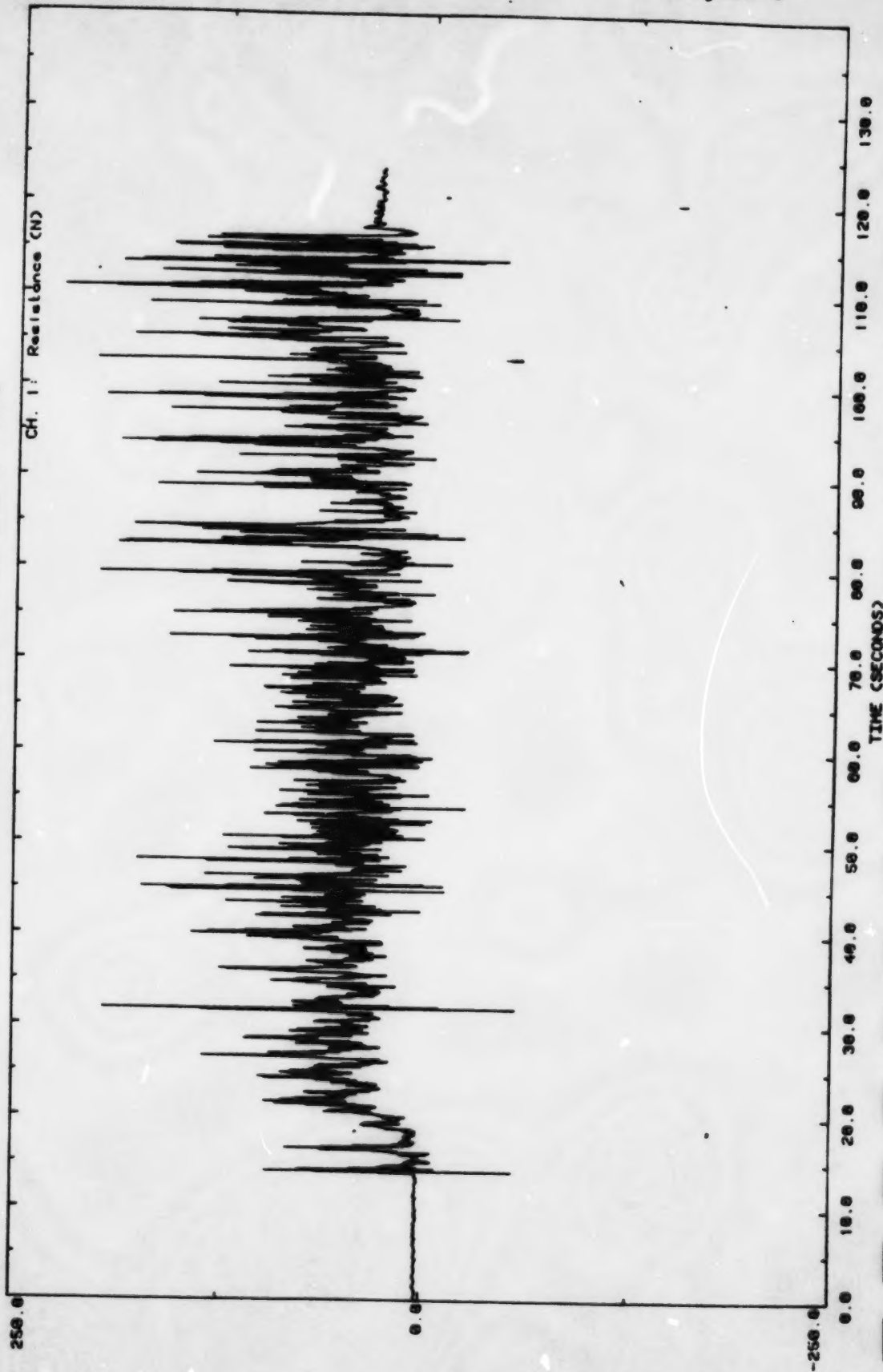


FIGURE 5 TOW FRAME ARRANGEMENT

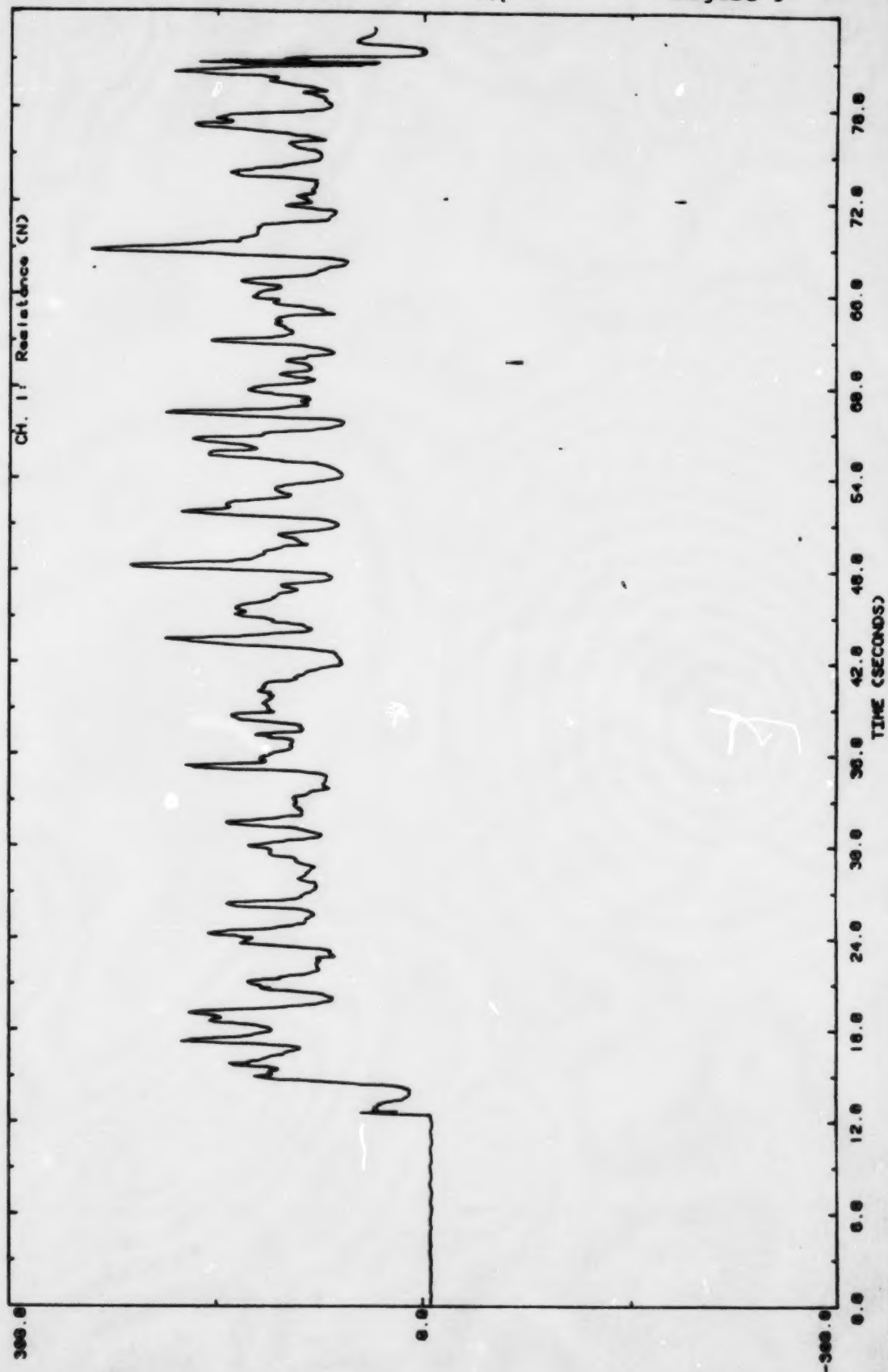


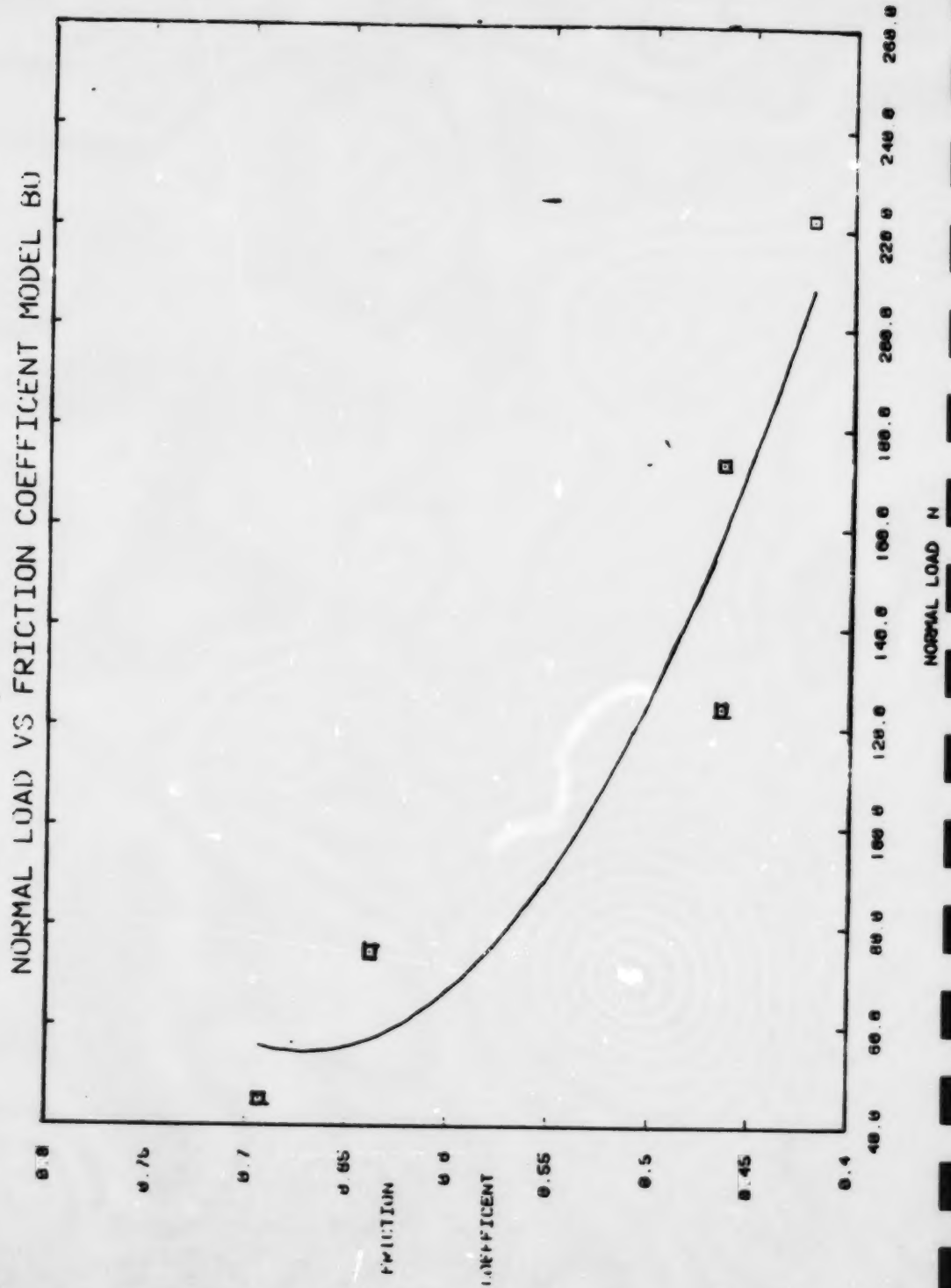


RUN 1 2-APR-1987 13:01:11 STRAKES MODEL B1 .15M/S



RUN 0 18-FEB-1987 12:42:36 MODEL 81 .15 M/S 30MM FEB 18 87





APPENDIX "B"

Interim Report

Wedge-Shaped Bows Fitted with Strakes

ICEBREAKING RESISTANCE OF
THREE WEDGE-SHAPED BOWS
FITTED WITH STRAKES

INTERIM REPORT

SUBMITTED TO
TRANSPORTATION DEVELOPMENT CENTRE
TRANSPORT CANADA
MONTREAL, (QUEBEC), CANADA

PREPARED BY
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CONSULTING ENGINEER,
STE-FOY, (QUEBEC), CANADA

MAY 1987

1.: INTRODUCTION

Field observations as well as theoretical analyses indicate that the over-all icebreaking performance of a vessel is generally lowered by significant ice crushing taking place near the aft end of the bow.

It has been suggested by the author that, by fitting strakes on the bow shoulder area of icebreaking vessels, a sufficient downward force will be exerted on the ice sheet to cause failure by bending thus reducing the likelihood of crushing at the shoulder.

The author has applied for a patent in regard to the above concept developed prior to performance of this contract.

In view of the evident economical benefits of thus enhancing the ice transiting capability of a vessel by simply fitting strakes near the aft end of the bow, the Transportation Development Centre sponsored the present study.

Besides analytical considerations, tests were conducted at the National Research Council, Institute for Marine Dynamics, in order to ascertain the actual strake effectiveness.

Following completion of the model tests, the data was analysed and predictions are made as a function of:

- 1.: waterline run angle;
- 2.: bow flare angle;
- 3.: strake inclination;
- 4.: strake size;
- 5.: strake draft.

2.: EXPERIMENTAL SET-UP AND CONDITIONS

The reader is referred to APPENDIX "A" for a complete description of the models and testing conditions. Also given and properly discussed in APPENDIX "A" are the results of the icebreaking resistance with and without strakes.

In the model tests, the range of variations of the considered parameters is as follows:

a.: waterline run angle....:	$7,5 \leq \alpha \leq 17,5$
b.: bow flare angle.....:	$0,0 \leq \beta \leq 25,0$
c.: strake inclination....:	$10,0 \leq \theta \leq 20,0$
d.: strake size.....:	$0,3 \leq f/h \leq 1,0$
e.: strake draft.....:	$1,0 \leq d'/h \leq 3,5$

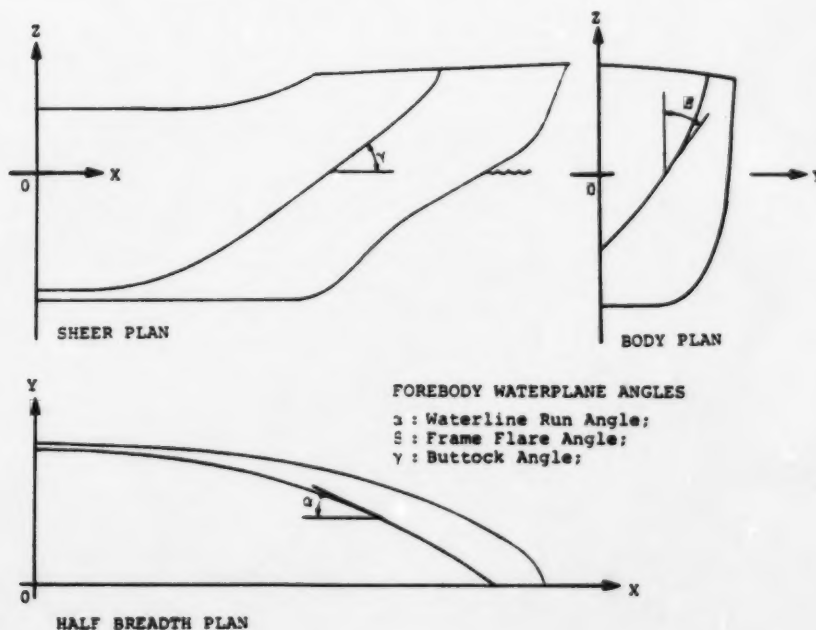


Figure 2.1.: Definition of Bow Angles.

3.: TRIGONOMETRIC RELATIONS

3.1.: WITHOUT STRAKES

The bow form geometry is generally defined by the X-Y-Z coordinates and three (3) sets of angles:

α : waterline run angle;
 β : frame flare angle;
 γ : buttock line angle.

The ice forces acting along the forebody length are readily resolved in their components if three (3) additional sets of angles are defined:

r : angle between perpendicular to waterline and OX-axis;
 s : angle between normal to shell plating and horizontal plane (YOX-plane);
 t : angle between normal to shell plating and OX-axis.

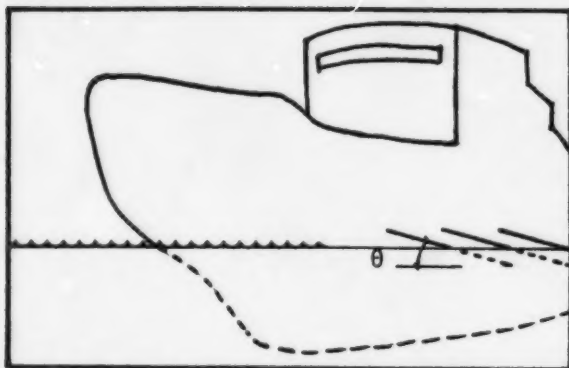
It has been shown by Carter [2] that these angles are related to α , β , and γ by the following equations:

$$\begin{aligned} r &= (90^\circ - \alpha) \\ s &= \tan^{-1}(\tan \beta \cos \alpha) \\ t &= \cos^{-1}(\cos r \cos s) \end{aligned}$$

3.2.: WITH STRAKES

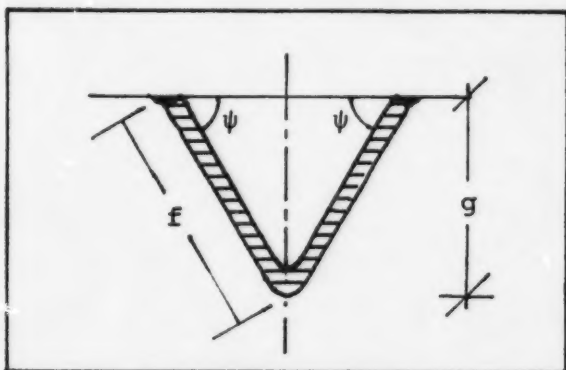
In the following section, asterisked letters will designate new sets of angles referred to the strake-ice interface. Making use of the symbols defined in Figure 3.1, we may obtain, after lengthy trigonometrical manipulations, the following relations:

$$\begin{aligned} \lambda &= \tan^{-1} \frac{1}{\cos s} \times \frac{\sin \theta}{\cot \psi + \tan s \cos \theta} \\ \xi &= \tan^{-1} \frac{1}{\cos s} \times \frac{\sin \theta}{\cot \psi - \tan s \cos \theta} \\ \alpha^* &= (\alpha + \xi) \\ \beta^* &= \tan^{-1}(\tan \alpha^* / \tan \gamma^*) \\ \gamma^* &= \tan^{-1} \frac{\tan \theta \cos s}{\cos \alpha (1 - \tan \alpha / \tan \alpha^*)} \end{aligned}$$

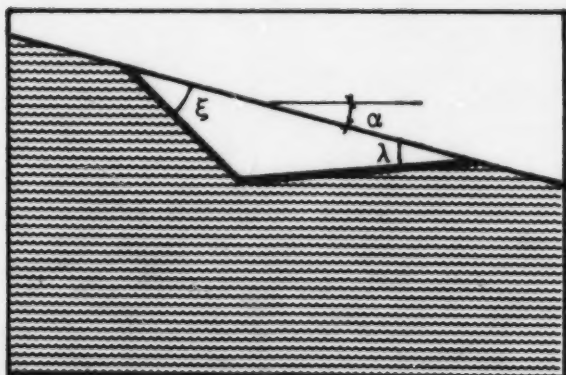


GENERAL "STRAKES" DISPOSITION

θ : "Strakes" inclination to the horizontal.



"STRAKES" CROSS-SECTION.



STRAKE INTERSECTING WATERPLANE

3.: TRIGONOMETRIC RELATIONS (Cont'd)

3.2.: WITH STRAKES (Cont'd)

$$r^* = (90^\circ - \alpha^*)$$

$$s^* = \tan^{-1} \tan (90^\circ - \gamma^*) \times \cos r^*$$

$$t^* = \cos^{-1} \cos r^* \cos s^*$$

TABLE 3.1 and Figure 3.2 compare the angles as measured directly on the three (3) models with the values calculated by the use of the above relations.

TABLE 3.1
COMPARISON BETWEEN MEASURED AND CALCULATED ANGLES

ANGLES	Model A		Model B		Model C	
	Meas. (°)	Calcul. (°)	Meas. (°)	Calcul. (°)	Meas. (°)	Calcul. (°)
λ	17,0	16,7	18,0	18,6	20,0	20,6
ξ	17,0	16,7	35,5	35,7	67,5	66,9
α^*	23,5	24,2	48,0	48,2	85,0	84,4
β^*	58,0	60,8	76,0	73,5	85,0	88,1
γ^*	14,0	14,1	17,0	18,3	20,0	19,0
r^*	66,0	65,8	42,0	41,8	5,0	5,6
s^*	59,0	58,5	66,0	66,1	70,0	70,9
t^*	78,0	77,6	73,0	72,4	72,0	71,0

The good correlation between measured and calculated values seems to ensure the rightness of the analytical formulae.

From Figure 3.1, it may be seen that, in order that strakes overlap one another, it is required that:

$$\lambda \geq \alpha$$

The minimum strakes inclination and maximum strakes spacing which satisfy this particular condition are given in Appendice "B".

3.: TRIGONOMETRIC RELATIONS (Cont'd)

3.2.: WITH STRAKES (Cont'd)

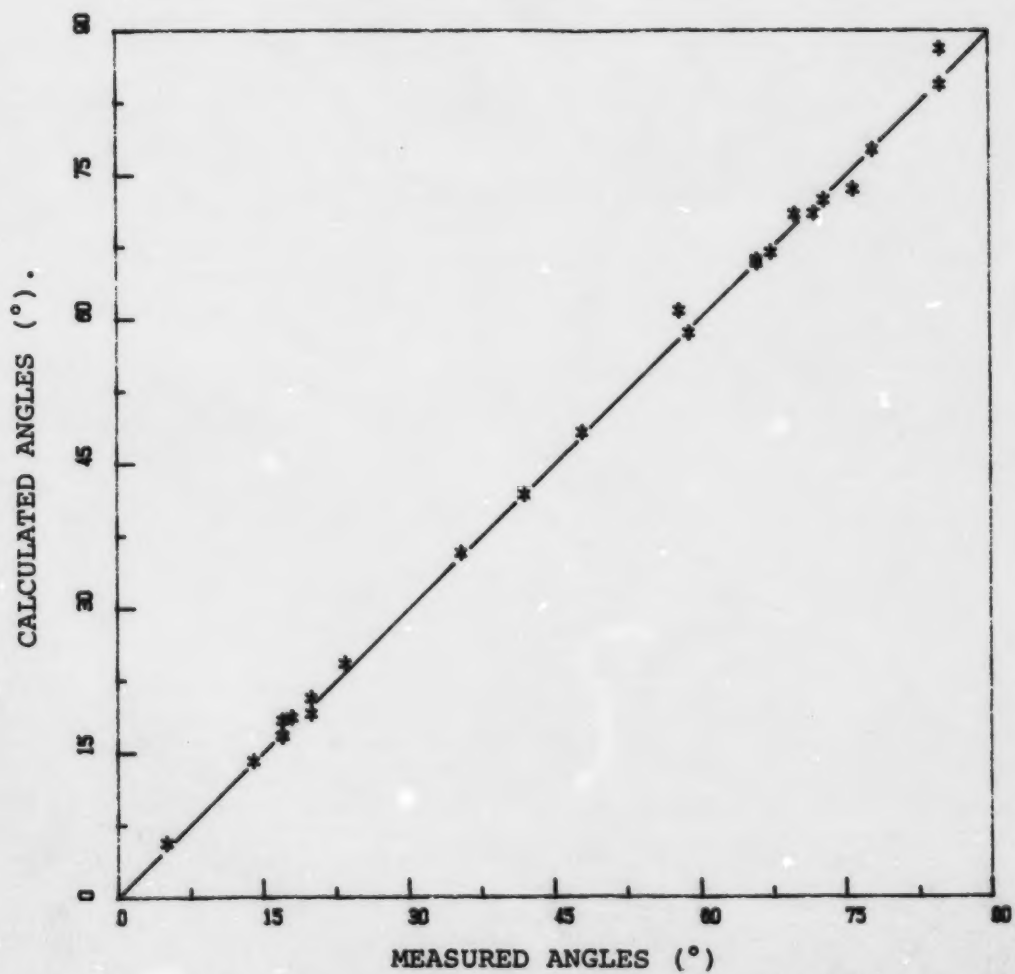


Figure 3.2.: Comparison between measured and calculated angles.

4.: ANALYTICAL CONSIDERATIONS

4.1.: GOVERNING EQUATIONS

In order to better isolate the icebreaking effect at the sides of the bow where the strakes were located, prior to all model tests, a 100 mm wide channel was sawn in the ice to remove the stem icebreaking component. Therefore, for the considered testing conditions, the ice resistance will correspond to the integration of forces acting along both sides of the wedge-shaped bows.

Using the analytical approach proposed by Carter [2], the ice resistance of the simplified bows, with and without strakes, may be predicted by evaluating successively the following equations with the proper angles defined in Chapter 3.

1.: Characteristic length, ℓ ,

$$\ell = 0,75 \left[\frac{E h^3}{12 \gamma (1 - \nu^2)} \right]^{\frac{1}{4}} \quad \text{EQ.: 4.1}$$

2.: Angle of the applied force with the horizontal plane, ψ ,

$$\psi = \sin^{-1} \frac{\sin(t - f')}{\sin t} \sin s \quad \text{EQ.: 4.2}$$

3.: Vertical failure load by bending, V ,

$$V = 0,38 \left(\tan \frac{\Delta r}{2} + \frac{\Delta y}{\ell \cos r} \right) \sigma h^2 \quad \text{EQ.: 4.3}$$

4.: Horizontal buckling load, H ,

$$H = \left(\Delta r + \frac{\Delta y}{\ell \cos r} \right) \gamma \ell^3 \quad \text{EQ.: 4.4}$$

4.: ANALYTICAL CONSIDERATIONS (Cont'd)

4.1.: GOVERNING EQUATIONS (Cont'd)

5.: Oblique failure load, P ,

$$P = \frac{V}{\left(\sin^2 \psi + \left(\frac{V^2}{H^2} \right) \cos^2 \psi \right)^{\frac{1}{2}}} \quad \text{EQ.: 4.5}$$

6.: Ice breaking force, R_b ,

$$R_b = 0,72 P \cos (t - f') \quad \text{EQ.: 4.6}$$

7.: Ice submerging force, R_s ,

$$R_s = 0,48 P \cos (t - f') \quad \text{EQ.: 4.7}$$

8.: Total Icebreaking Resistance, R_t , at creeping speed:

$$R_t = 1,2 P \cos (t - f') \quad \text{EQ.: 4.8}$$

9.: Ice Breaking and Ice Submerging Components:

$$R_b = 60\% R_t \quad R_s = 40\% R_t \quad \text{EQ.: 4.9}$$

In the above equations, the symbols have the following meaning:

- E : Young's modulus;
- h : Ice thickness;
- γ : Unit weight of water;
- ν : Poisson's ratio;
- f' : $\arctan f$; f being the kinetic friction coefficient;
- Δr : 0 for the straight sides of the wedge-shaped bows;
- Δx : 0,5 m

r, s, t : angles defined in Chapter 3.

A computer program was written to facilitate the evaluation of these equations.

5.: EXPERIMENTAL RESULTS

5.1.: ELASTIC MODULUS

As shown in Figure 5.1, the relation between the elastic modulus, E , and the ice strength, σ , is closely approximated, for the range of variations observed in our testing program, $19 \leq \sigma \leq 42$ kPa, by the following equation:

$$E \text{ (kPa)} = 178 \sigma^{1.5} \quad \text{EQ.: 5.1}$$

The characteristic length will be evaluated by introducing the above relation into EQ.: 4.1.

TABLE 5.1
ELASTIC MODULUS VERSUS ICE STRENGTH

ICE SHEET #	Flexural Strength (kPa)	Elastic Modulus (MPa)
1	19	12,4
2	32	37,1
3	48	62,0
4	49	58,0

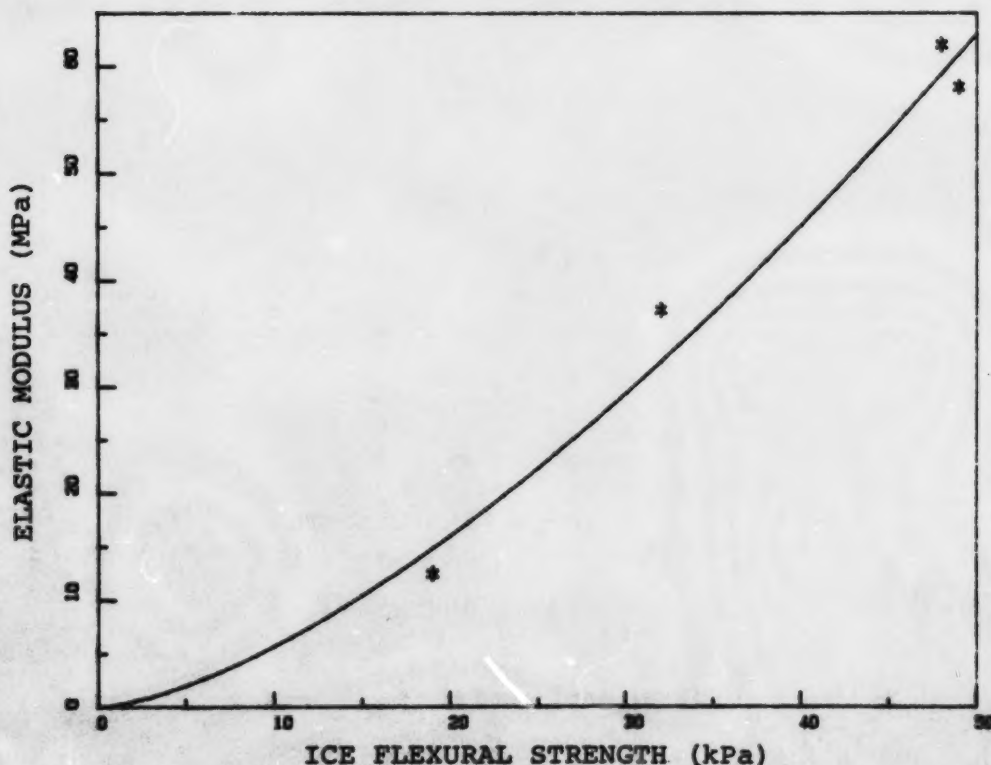


Figure 5.1.: Experimental Relation between Elastic Modulus and Ice Flexural Strength.

5.: EXPERIMENTAL RESULTS (Cont'd)

5.2.: OPEN WATER RESISTANCE

It can be seen in Figure 5.2 that, at the testing speed in ice, 0,15 m/s, the open water resistance of all models remain smaller than the measurements error of about 3 @ 4 N.

Therefore the open water resistance will be considered negligible, and the total icebreaking resistance will correspond to the ice forces only.

TABLE 5.2

OPEN WATER RESISTANCE (N) VERSUS MODEL SPEED (m/s).
(Draft = 175 mm)

MODEL	Carriage Speed (m/s).			
	0,00	0,15	0,50	0,85
MODEL A0	0,00	0,68	4,80	12,77
MODEL A2	0,00	1,94	6,11	14,15
MODEL B0	0,00	1,72	6,18	12,41
MODEL C0	0,00	1,13	5,90	12,83
MODEL C2	0,00	2,02	6,78	13,76

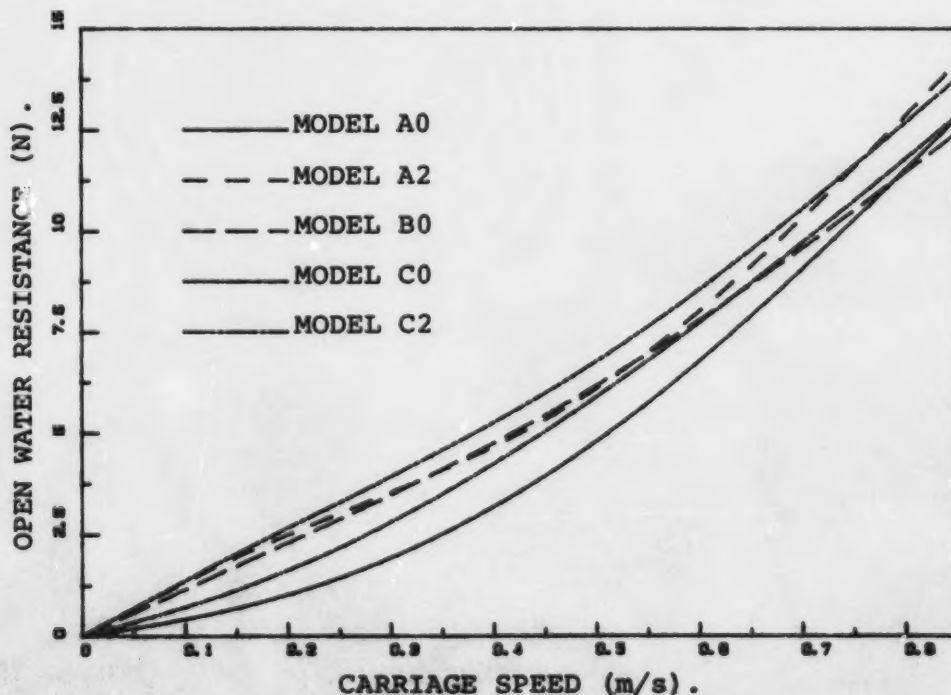


Figure 5.2.: Open Water Resistance for the series of Models.

5.: EXPERIMENTAL RESULTS (Cont'd)

5.3.: FRICTION COEFFICIENT

Friction coefficient between the ice and the hull of the models was measured at various normal loads by measuring the tangential force required to pull a loaded ice sample. The model-ice friction coefficient was found to vary between:

$$0,42 \leq f \leq 0,7$$

which is unrealistically high for a very smooth plywood surface with a varnish coating.

For a similar simplified bow form, Tatinclaux [] reported an average friction coefficient of:

$$\bar{f} = 0,054 \pm 0,011 \quad \text{top of ice}$$

$$\bar{f} = 0,033 \pm 0,002 \quad \text{bottom of ice}$$

In IMD tests, the ice samples were pulled by hand on a relatively short distance and the inertial forces may have been relatively important. In the series of tests at CRREL, the sample holder, loaded with weights, was pulled, at a constant speed, by a motor-driven screw jack.

Since the coefficient of dynamic friction between the ice-water mixture rubbing against the hull of the models is an unknown variable, rather than use a contrived estimate, it was set to its most commonly used value:

$$f \approx 0,1 \quad \text{and} \quad f' \approx 5,7^\circ$$

Since the component due to frictional forces is generally a small part of the total icebreaking force, it is thought that even an appreciable error in f will have little effect on the total resistance.

5.: EXPERIMENTAL RESULTS (Cont'd)

5.4.: RESISTANCE RESULTS

The video records of the tests clearly show that the failure mode differs depending upon the angle of application of the resultant force acting at the ice edge. Under in-plane forces, the ice cover fails by buckling whereas, under inclined forces, the ice failure occurs in bending. In the following sections, we will consider successively these two (2) failure modes.

5.4.1 FAILURE BY BUCKLING

In the first series of tests, the drafts were set at 175 mm so that the ratio "strake immersion/ice thickness", d'/h , was about 3,5 for all models with strakes. As discussed in Annex A (page 3), the ice is then prevented by the strakes from sliding down the hull. Thus, as the model advanced, the increasing width of the bow section induced high in-plane forces which caused failure by buckling.

In the second series of tests, the draft of the Model A was varied to provide differing degrees of strake immersion. For all models with strakes, the observed mode of failure was buckling for $d'/h > 1,9$

Furthermore, failure by buckling was also observed for the Model A0 without strakes, the sides of the model being vertical, the direction of load is then horizontal which resulted in in-plane forces.

For the model without strakes, A0, the upper surface of the ice sheet being not supported, the instability deflection occurs more readily in the upward direction. The total ice-breaking resistance is then likely to correspond to the ice breaking component plus a little part of the usual submergence component.

For the series of models with strakes, the total ice-breaking should correspond to the ice breaking component plus an ice submerging component increasing with the ratio d'/h .

The effect of the strake immersion on buckling load was evaluated from the series of tests given in TABLE 5.3 by the following relation:

$$R_t = F(d'/h) \times \text{BUCKLING LOAD}$$

and found to be well approximated by: (Figure 5.3)

$$F(d'/h) = 0,7 + 0,03(d'/h)^2$$

5.: EXPERIMENTAL RESULTS (Cont'd)

5.4.: RESISTANCE RESULTS (Cont'd)

5.4.1 FAILURE BY BUCKLING (Cont'd)

TABLE 5.3

EFFECT OF STRAKE IMMERSION ON BUCKLING LOAD

MODEL	Model Draft (mm)	Measured Resistance (N)	Ratio d'/h	Function $F(d'/h)$
A0	175	77,47	0,00	0,58
A0	100	127,80	0,00	0,81
A2	125	135,30	1,90	0,89
A2	150	145,10	2,77	0,94
A2	175	133,42	3,89	1,05
B2	175	129,58	3,71	1,34
C2	175	137,27	3,89	1,13

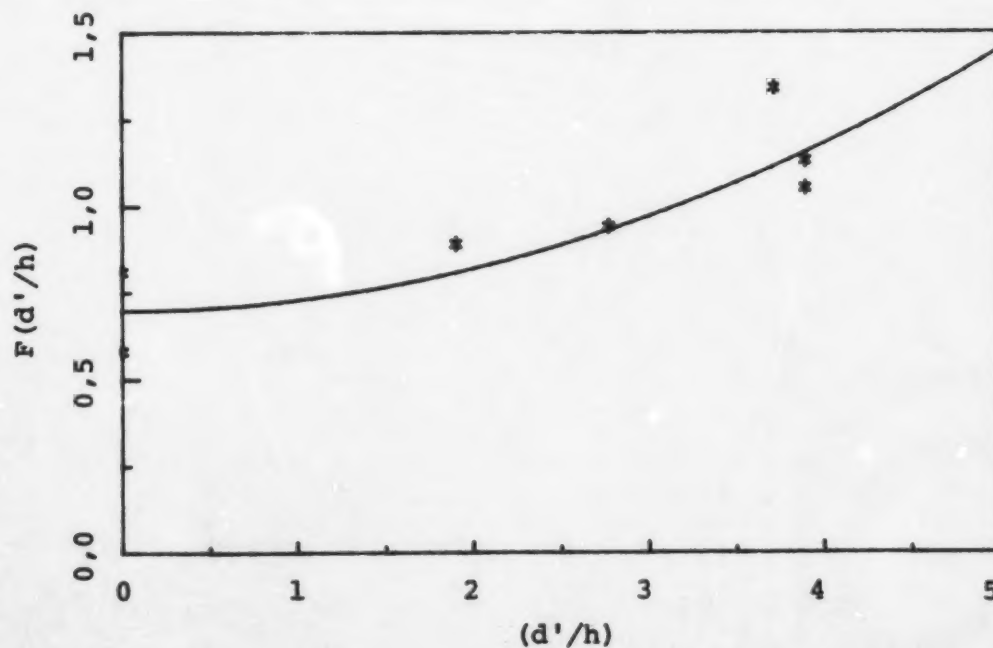


Figure 5.3.: Influence of Strake Immersion on Buckling Load.

5.: EXPERIMENTAL RESULTS (Cont'd)

5.4.: RESISTANCE RESULTS (Cont'd)

5.4.2 FAILURE IN BENDING

For the B and C models without strakes, the failure of the floating wedges pressing against the inclined sides occurred in bending and should be directly predicted by the use of EQ.: 4.1 @ 4.9.

For all models with strakes, when the ratio "strake immersion/ice thickness", d'/h , is close to 1, the failure seems to occur as follows:

- 1.: As the ice comes into contact with the strakes, it is successively deflected, broken and sunk by the strakes;
- 2.: Most ice pieces are then further submerged and slide along the bare sides of model hull;
- 3.: Few ice pieces are prevented by the strakes from following a smooth path down along the hull sides.

The total icebreaking resistance should therefore be written in the following form:

$$R_t = R_t^* + m R_i + n H_i$$

where m & n : coefficients

R_t^* : ice forces corresponding the the strake-ice interface;

R_i : ice forces corresponding to the hull-ice interface;

H_i : buckling load evaluated for in-plane applied forces.

The values of m and n were determined from the test results given in TABLE 5.4. The total icebreaking resistance for models with strakes was found when the ratio "strake immersion/ice thickness" is close to 1 to be closely approximated by:

$$R_t = R_t^* + 0,45 R_i + 0,04 H_i$$

EQ.: 5.2

Figure 5.4 compares the values predicted by EQ.: 5.2 with the actual measurements of TABLE 5.4.

5.: EXPERIMENTAL RESULTS (Cont'd)

5.4.: RESISTANCE RESULTS (Cont'd)

5.4.2 FAILURE IN BENDING (Cont'd)

TABLE 5.4

ICE RESISTANCE FOR MODELS WITH STRAKES AT DRAFT = 100 mm

MODEL	Draft (mm)	Ice thickness (mm)	Ice strength (kPa)	Measured Resistance
MODEL A2	100	28,9	34	97,9
MODEL B1	100	29,9	42	52,6
MODEL B2	100	29,9	40	53,6
MODEL B3	100	29,9	38	59,1
MODEL C2	100	28,9	32	37,3

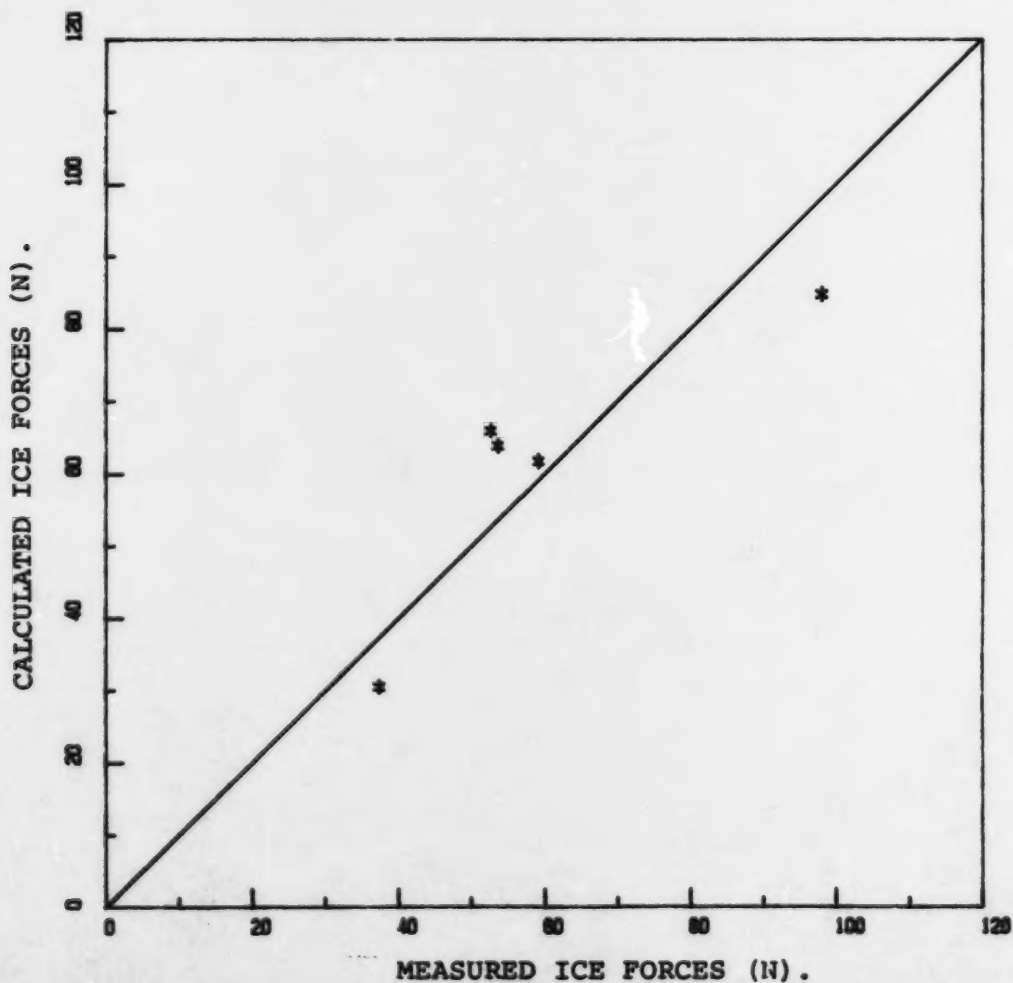


Figure 5.4.: Comparison between Calculated Ice Forces and Measured Ice Forces for the series of models with strakes at draft = 100 mm.

6.: TESTING THE PREDICTIVE MODEL

6.1.: COMPARISON WITH MODEL DATA

The predictive equations presented in the previous section may now be tested to determine their prediction ability. The values predicted by the equations are compared to the measured values in Figure 6.1. The comparison indicates a relatively good ability of prediction.

TABLE 6.1

RESULTS OF ALL MODEL TESTS.

MODEL	DRAFT (mm)	THICKNESS (mm)	STRENGTH (kPa)	R_{meas} (N)	R_{calc} (N)
A0	175	27,0	32	77,47	93,66
A2	175	27,0	30	133,42	147,18
B0	175	28,3	22	26,80	65,99
B1	175	28,3	19	103,12	102,21
B2	175	28,3	20	129,58	107,74
B3	175	28,3	21	144,48	113,00
C0	175	27,0	27	19,30	34,21
C2	175	27,0	28	137,27	139,63
A0	100	28,9	35	127,80	110,57
A2	100	28,9	34	97,90	84,69
A2	125	28,9	33	135,30	122,51
A2	150	28,9	34	145,10	143,91
B0	100	29,9	35	74,40	95,19
B1	100	29,9	42	52,60	65,89
B2	100	29,9	40	53,60	63,78
B3	100	29,9	38	59,10	61,64
C0	100	28,9	33	26,80	42,29
C2	100	28,9	32	37,30	30,35

6.: TESTING THE PREDICTIVE MODEL (Cont'd)

6.1.: COMPARISON WITH MODEL DATA (Cont'd)

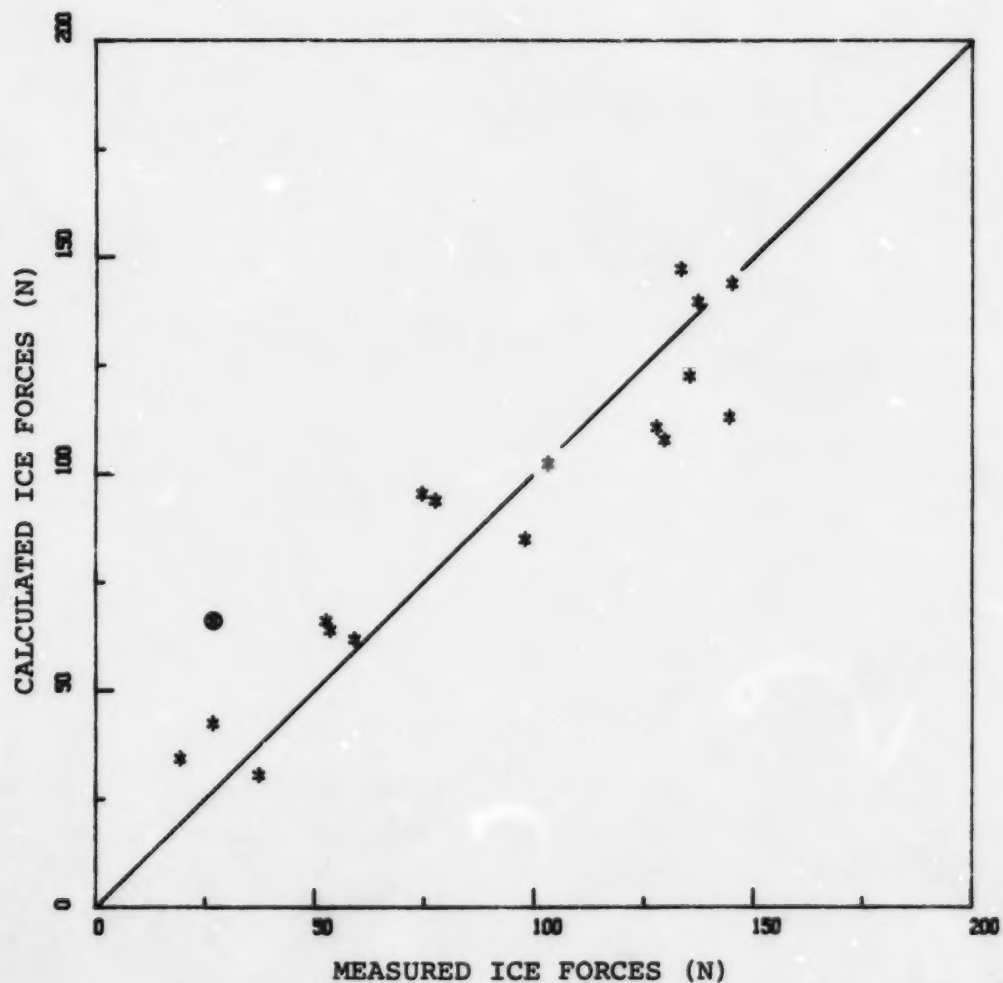


Figure 6.1.: Comparison between Calculated and Measured Ice Forces.

6.: TESTING THE MODEL (Cont'd)

6.2.: PREDICTION OF STRAKES EFFICIENCY

The effect of fitting strakes on the bow shoulder areas of icebreaking vessels have been predicted by the use of the proposed equations. In Figure 6.2, the relative resistance:

$$\frac{\text{RESISTANCE WITH STRAKES}}{\text{RESISTANCE WITHOUT STRAKES}}$$

is plotted versus the waterline run angle, α , and the bow flare angle, β , for the optimal value of the strake inclination, θ , given in Appendix B.

The assumed values are as follows:

Ice strength.....	σ	:	30kPa
Ice thickness.....	h	:	30mm
Friction Coefficient..	f	:	0,1
Strake Draft.....	d'/h	:	1,0

6.: TESTING THE PREDICTIVE MODEL (Cont'd)

6.2.: PREDICTION OF STRAKES EFFICIENCY (Cont'd)

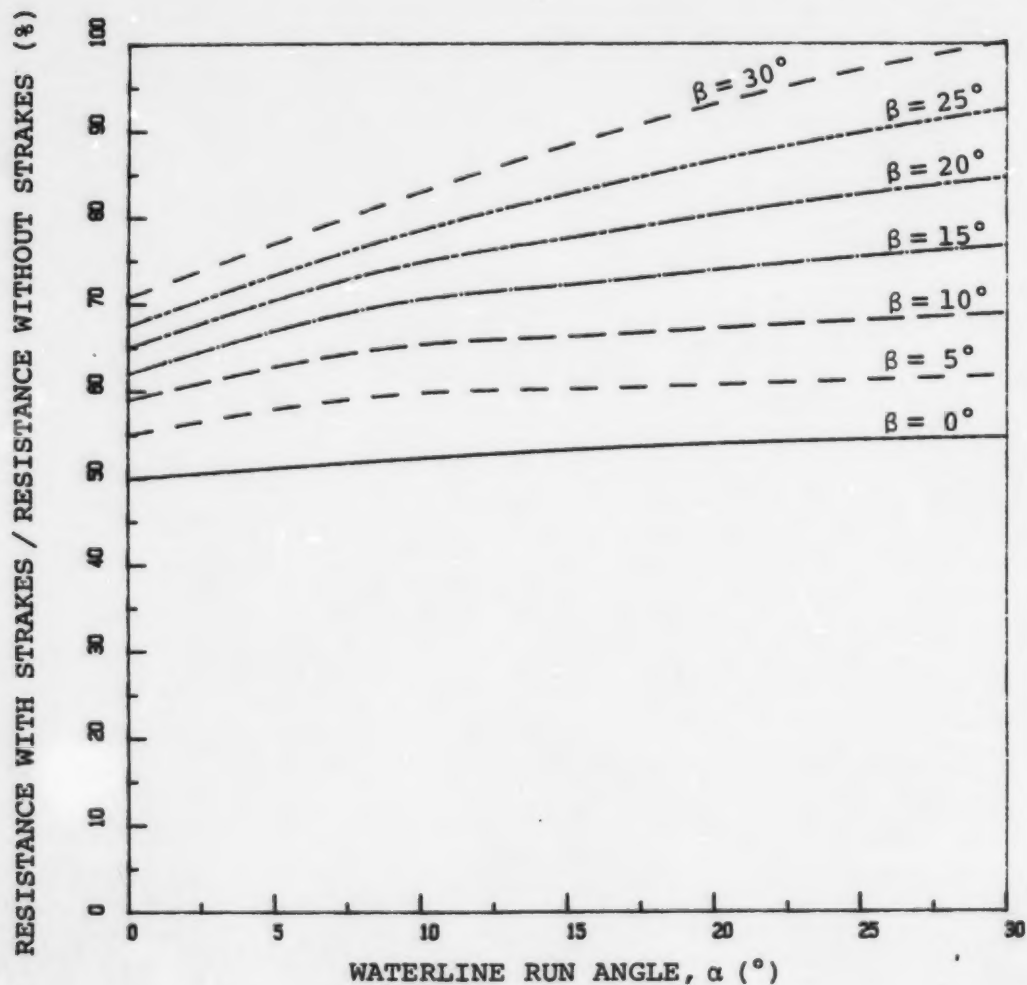


Figure 6.2.: Maximum strake efficiency as a function of waterline run angle, α , and bow flare angle, β , for the optimal strake inclination.

7.: CONCLUSIONS

Based on the results of our model tests program and the analysis thereof, the following main conclusions may be drawn:

- 1.: The basic equations of the Carter's model may be used to closely predicted the effect of hull geometry and ice characteristics on icebreaking resistance.
- 2.: By fitting strakes on the aft part of a bow, the icebreaking resistance associated with forces acting at the shoulder area may be reduced by a factor as high as 50%.
- 3.: Observations during model tests have evidenced that the failure mode is different in full-scale and model tests. In model tests, failure occurs by buckling when the applied load is close to the horizontal. In the field, ice sheets thicker than 0,3m always fails by crushing. [1] Full-scale crushing loads are dangerously underestimated by scaling up model buckling loads.
- 4.: Additional laboratory studies are required to determine if the increased ice resistance of the models for deeper strakes immersion is compounded by the fact that the models were restrained in pitch and heave.
- 5.: Additional model tests are also required to estimate the detrimental effect of strakes on the open water performance of actual ships.

APPENDIX "C"

IMD Second Report.

Louis S. St.Laurent with Strakes.

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LOUIS S. ST. LAURENT WITH STRAKES

1.0 INTRODUCTION

Model tests for the Louis S. St. Laurent fitted with strakes were carried out at the Institute for Marine Dynamics (IMD) at the request of Dr. Donald Carter, Ingénieur-Conseil, of Ste -Foy, Québec. The concept of strakes to reduce ship resistance in ice was explored in an series of model tests on simplified forms (Ref. 1). An extensive series of model tests was carried out at IMD to evaluate the performance of the Louis S. St. Laurent in calm water (Ref. 2) and in level ice (Ref. 3). The purpose of the present test series was to determine the effectiveness of strakes fitted on the bow of the Louis S. St. Laurent. The model was tested in calm water and in level ice, each at two drafts, and the results are compared with the corresponding tests on the same model in the previous test series.

2.0 MODEL DESCRIPTION

The model, 395A, is a 1:15 scale model constructed at IMD from lines supplied by the Canadian Coast Guard. Details of the model construction are given in Reference 3. The model was fitted with bare hubs and cones. The model descriptions for the test drafts, 7.5m and 8.5m full scale, are given in Tables 1 and 2.

The strakes were positioned on the bow according to the drawings supplied by Dr. Carter. The strakes were bolted through the hull, filled, sanded, and finished to a friction coefficient similar to that of the hull. The location of the strakes is given in Figure 1, and the model with strakes applied is shown in Figure 2.

3.0 CALM WATER RESISTANCE

3.1 Resistance Tests

The model was fitted with turbulence generators, ballasted to

level draft with high GM, and towed at constant speeds in calm water. Towing force and carriage speed were averaged over the steady state portion of the run. Video records were made showing water surface at the strakes and at the stern for some runs.

3.2 Results

The results for the 0.567 m draft are given in Table 3, and for the 0.500 m draft in Table 4. The Froude Number, FN, is based on the LBP, making it the same for both drafts. The resistance coefficient, CTM, is based on the actual wetted areas given in Tables 1 and 2. The datapoints are shown as resistance plotted against speed in Figures 3 - 5, and as CTM against FN, with a fair line fitted through the data, in Figures 6 and 7.

4.0 LEVEL ICE RESISTANCE

4.1 Resistance Tests

The ice tank tests were carried out according to the procedures described in Reference 4. The ice sheet was grown from a wet seed to a target thickness of 67 mm, and tempered to a target strength of 30 kPa. The percentage concentrations of EG/AD/S for this test were 0.39/0.027/0.0.

The model test conditions are shown in Tables 1 and 2. The towing point was 0.587 m above the baseline at the LCG, and the yaw restraint was located 2.08 m aft of the LCG, on the roll axis. The GM was determined by inclining. The radius of gyration, k, was calculated from the pitch period of the model in the water, 2.5 sec., using the estimate (Ref. 5)

$$\tau = 2\pi k \sqrt{(1+a)/g \times GM},$$

where $a = 0.2$.

Ship resistance in level ice was measured at two model speeds at each of the two drafts. Level ice was then sawn into the

bow pattern, and ship resistance in the presawn ice measured at two model speeds at each draft. Video cameras fore and aft, above and below the surface, recorded ice motion at the strakes and at the stern for every run.

4.2 Results

Ice properties were measured throughout the test day. The full report on Ice Mechanical Properties is contained in Appendix 1. The flexural strength, σ_f , was measured at the location of each level ice test, and the tempering curve used to adjust these values to the strength at test time. The thickness h was averaged for each test location. These values are reported in Table 5. Values for other properties are:

$$E = 73.5, \quad E/\sigma_f = 2218, \quad \sigma_f/K_{1c} = 7.3$$

$$\sigma_s = 50, \quad \sigma_c = 110, \quad \rho = 0.935$$

The time series, sampled at 50 Hz, for resistance and carriage speed are shown in Figures 8 and 9. The data are presented in Table 5. "Track" is the interval in the tank over which the averages of thickness and resistance were taken. Strengths were measured at each test location. A strength value of zero indicates the model towed through presawn ice.

The test results were adjusted in Table 6 to give resistances at the reference conditions of $h = 67$ mm and $\sigma = 25$ kPa. For small increments, the adjustments are linear in both h and σ . In the headings of Table 6, $R(h, \sigma)$ is the resistance at thickness h and strength σ , h^* is the thickness of the presawn ice, $R(h^*, 0)$ is the submergence resistance, and $B(h, \sigma)$ is the breaking resistance. The algorithm is:

$$R(h, 0) = R(h^*, 0) \times h/h^*$$

$$B(h, \sigma) = R(h, \sigma) - R(h, 0)$$

$$B(h, 25) = B(h, \sigma) \times 25/\sigma$$

$$R(67, 25) = R(h, 25) \times 67/h$$

The level ice and submergence resistances are plotted against speed in Figure 10. The curves in the figure are resistances for the bow with no strakes, from Reference 3.

The video records show the deformation and displacement of the ice around the bow. As ice pieces move aft relative to the hull, the strakes deflect them downward below the ice sheet. Thus jamming between the shoulder and the intact ice sheet is avoided.

5.0 COMPARISON WITH ORIGINAL BOW

The calm resistance for the original bow with no strakes, at 0.600 m level draft (Ref. 2), is shown as the curve in Figures 3 and 4, together with the points from the present test series. For the model at 0.500 m draft, additional resistance due to the strakes is offset by a reduction in resistance due to reduced displacement. For the model at 0.567 m draft, the strake resistance appears at about 1.0 m/s model speed, and increases with speed. At 2.5 m/s, the additional resistance due to strakes is approximately 9%. Alternatively, it may be considered that with strakes, the speed is 2% less for the same resistance.

Level ice resistance and submergence resistance for the model without strakes, at 0.600 m draft, are given in Reference 3. The values were scaled linearly to the reference thickness and the best fit straight lines are shown in Figure 10. Since the bow entry angles and beams for the 0.567 m and 0.600 m drafts are almost equal, the resistances are comparable. Both the total ice resistance and the submergence resistance are reduced by the action of the strakes. Because of the limited number of different speeds at which measurements were taken, both in the present test series and in the previous, the speed dependence of the resistance reduction is not clear. At 0.5 m/s, the reduction is 8.5% of the level ice resistance and 11% of the submergence resistance with no strakes.

6.0 CONCLUSIONS

The test program shows that the installation of strakes on the bow of the model of the Louis S. St. Laurent had a significant effect on level ice performance. The numerical data shows a reduction in resistance for the model with strakes and the video record shows the influence of the strakes on ice submergence and clearing. The ice resistances were lowest for the shallow draft with strakes, but it is not possible to determine the reductions due to draft and strakes separately.

Because the test program was brief, the speed dependence of the resistance reduction is not clear. The effect of the strakes is dependent on the flexural rigidity of the model ice sheet, which in turn is highly strain rate dependent within the range of strain rates of present tests. Hence speed may be an important factor. Furthermore, the flexural rigidity of full scale ice sheets is also strain rate dependent, but the time function is different from that for the model scale. Further information is required before full scale significance of the results of the tank tests can be determined.

7.0 REFERENCES

- 1 COLBOURNE, B. "Model Tests in Ice of a Simplified Form Fitted with Strakes", IMD Report TR-AVR-06, April 1987.
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- 3 SPENCER, D , "Ice Model Tests on CCGS Louis S. St. Laurent Phase I", IMD Report TR-AVR-01, March 1987.
- 4 JONES, S. J , et al "Ice Tank Model Test Methods at IMD", IMD Report LM-AVR-**, August 1987.

5. BATTACHARYYA, R. The Dynamics of Marine Vehicles, Wiley-Interscience Publication, 1978.

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LIST OF SYMBOLS

<u>SYMBOL</u>	<u>QUANTITY</u>	<u>UNITS</u>
A_w	model wetted surface area	m
$B(h, \sigma)$	breaking component of ice resistance	N
CG	location of centre of gravity	
CTM	Resistance coefficient. $CTM = 2R/\rho_w v A_w$	
E	effective elastic modulus for ice sheet	MPa
GM	height of metacentre above CG	m
g	acceleration due to gravity	m/sec ²
h	ice thickness	mm
K_{Ic}	fracture toughness	kPa-m ^{1/2}
k	radius of gyration	m
R	resistance	N
$R(h, \sigma)$	R at ice thickness h and strength σ	N
v	speed	m/sec
ρ_i	ice density	kg/m $\bar{\rho}_i$
ρ_w	water density	kg/m $\bar{\rho}_w$
σ_f, σ	flexural strength	kPa
σ_c	uniaxial compressive strength	kPa
σ_s	shear strength	kPa
τ	period of oscillation	sec

LOUIS S. ST. LAURENT

MODEL DESCRIPTION AND TEST CONDITION 1

scale	1:15	
length between perpendiculars	6.787	m
waterline beam at midships	1.621	m
draft at midships	0.567	m
draft at aft perpendicular	0.567	m
draft at fwd perpendicular	0.567	m
wetted surface area	11.764	m
displacement	3596	kg
CG fwd of midships	-0.080	m
CG above keel	0.602	m
transverse GM	0.147	m
radius of gyration in roll	0.436	m

LOUIS S. ST. LAURENT

MODEL DESCRIPTION AND TEST CONDITION 2

scale	1.15	
length between perpendiculars	6.787	m
waterline beam at midships	1.608	m
draft at midships	0.500	m
draft at aft perpendicular	0.500	m
draft at fwd perpendicular	0.500	m
wetted surface area	10.374	m
displacement	3024	kg
CG fwd of midships	-0.069	m
CG above keel	0.592	m
transverse GM	0.168	m
radius of gyration in roll	0.466	m

CALM WATER RESISTANCE 0.567 M DRAFT

KEE MODEL 9954 STR LOUIS ST. LAURENT - COND 1 12-APR-88

RUN NUMBER
TEST TEMPERATURE (195 C)
CARRIAGE SPEED (1/2)
RESISTANCE (N)
FROUDE NUMBER
CTM X 10**3

1.00000	15.90000	2.302131	240.7832	0.282186	7.92653
2.00000	15.90000	2.013178	146.2675	0.247010	6.13143
3.00000	15.90000	1.726289	96.2428	0.211600	5.49771
5.00000	15.90000	1.294518	49.5728	0.158675	5.06627
6.00000	15.90000	1.006399	32.3635	0.123421	5.43407
7.00000	15.90000	0.718138	16.9061	0.086026	5.58044
9.00000	15.90000	0.575372	12.2576	0.070526	5.30303
10.00000	15.90000	0.483476	6.7867	0.053133	5.14647
11.00000	15.90000	0.238340	2.7884	0.035405	5.68530
14.00000	15.90000	0.390474	5.9867	0.047862	6.66417
15.00000	15.90000	0.504842	8.5679	0.061881	5.72276
16.00000	15.90000	0.647671	13.4104	0.079388	5.44218
18.00000	15.90000	0.862001	23.4995	0.105060	5.38144
19.00000	15.90000	1.151092	41.5320	0.141095	5.33585
20.00000	15.90000	1.437987	62.3490	0.176261	5.13287
22.00000	15.90000	1.871936	122.1815	0.229453	5.93539
23.00000	15.90000	2.160500	179.0179	0.264823	6.52673
24.00000	15.90000	2.591193	465.9620	0.317615	11.81386
26.00000	15.90000	2.311907	401.0411	0.307897	10.61988
27.00000	15.90000	2.413635	325.9224	0.295851	9.52383
28.00000	15.90000	2.249943	217.7348	0.275787	7.32193
30.00000	15.90000	2.033917	162.9785	0.255681	6.37642
31.00000	15.90000	1.593082	82.2013	0.195517	5.49988
32.00000	15.90000	1.295618	51.7812	0.158810	5.25120
41.00000	15.90000	2.235642	288.4103	0.289969	8.77311

CALM WATER RESISTANCE 0.500 M DRAFT

RES MODEL 395A STR LOUIS ST. LAURENT - COND 2 13-APR-88

RUN NUMBER
TEST TEMPERATURE (deg C)
CARRIAGE SPEED (m/s)
RESISTANCE (N)
TROWDE NUMBER
CTM X 10**3

1.00000	15.60000	2.303782	236.8802	0.282386	8.61539
2.00000	15.60000	2.015974	138.7455	0.247108	5.58139
3.00000	15.60000	1.726443	39.4726	0.211617	5.79577
5.00000	15.60000	1.294352	48.1539	0.158659	5.53260
6.00000	15.60000	1.006760	29.3191	0.123404	5.58376
7.00000	15.60000	0.710076	16.2670	0.085018	6.08963
9.00000	15.60000	0.575321	11.0314	0.070320	6.43335
10.00000	15.60000	0.433536	5.4266	0.053141	5.57327
11.00000	15.60000	0.385925	2.4263	0.035415	5.51551
12.00000	15.60000	0.389840	4.8384	0.047785	6.14551
14.00000	15.60000	0.505184	7.5639	0.061923	5.72101
15.00000	15.60000	0.647954	12.6314	0.079423	5.80756
17.00000	15.60000	0.862283	23.7206	0.105694	5.15820
18.00000	15.60000	1.151148	37.7288	0.141102	5.49591
19.00000	15.60000	1.438157	59.6671	0.176282	5.56867
21.00000	15.60000	1.871829	114.2615	0.229403	6.29703
22.00000	15.60000	2.159709	173.1632	0.264726	7.16628
23.00000	15.60000	2.591192	421.4120	0.317615	12.11537
25.00000	15.60000	2.511515	372.0321	0.307849	11.38513
26.00000	15.60000	2.413083	303.7111	0.295784	10.06804
27.00000	15.60000	2.249468	206.9623	0.275723	7.29515
29.00000	15.60000	2.085318	153.0979	0.255608	6.79600
30.00000	15.60000	1.594629	78.1200	0.195462	5.93023
31.00000	15.60000	0.861612	22.7497	0.105612	5.91536
33.00000	15.60000	1.594743	77.8460	0.195476	5.90859
34.00000	15.60000	1.512511	70.5253	0.185396	5.93082
35.00000	15.60000	1.437105	62.0546	0.176153	5.79997
36.00000	15.60000	1.727335	91.4712	0.211728	5.91780
38.00000	15.60000	2.365268	274.6431	0.289923	9.47626
39.00000	15.60000	0.574638	9.8503	0.070436	5.75825
40.00000	15.60000	0.390033	4.5421	0.047803	5.76350
41.00000	15.60000	0.719299	15.6308	0.088167	5.71986

TABLE 5

ICE TEST RESULTS

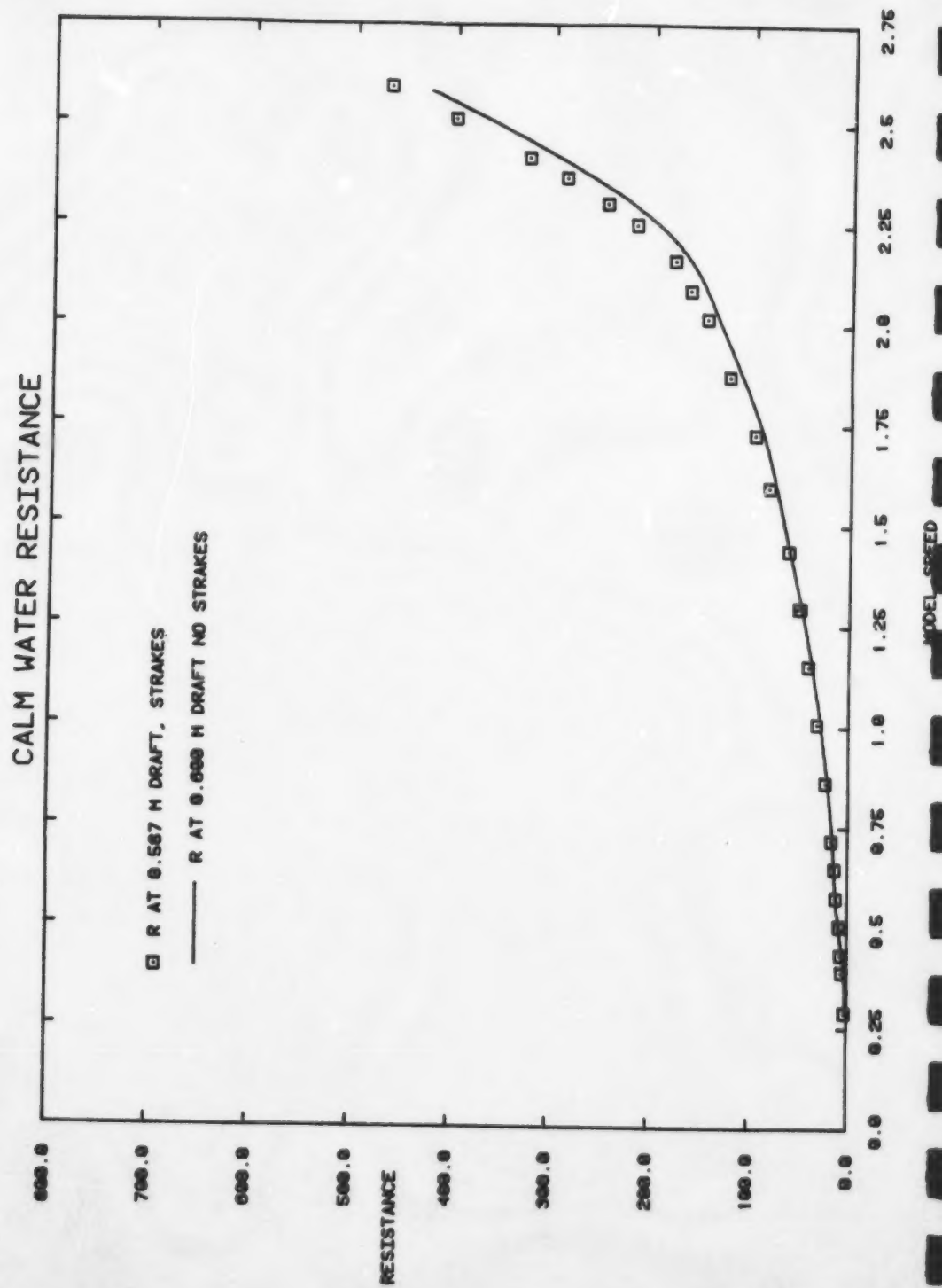
RUN #	DRAFT (m)	V (m/s)	TRACK (m)	h (mm)	σ (kPa)	R (N)
1	0.500	0.25	8.2 - 14.6	67.3	25	446
1	0.500	0.80	25 - 33	65.8	31	597
2	0.567	0.25	40 - 46	66.6	22	443
2	0.567	0.80	56 - 65	66.7	25	642
4	0.567	0.25	7.8 - 14.6	66.0	0	158
4	0.567	0.80	25 - 33	65.0	0	279
5	0.500	0.25	40 - 46	65.2	0	149
6	0.500	0.80	58 - 65	66.1	0	269

TABLE 6

ICE RESISTANCE AT 67 mm AND 25 kPa

RUN #	V (m/s)	R(h, σ) (N)	h* (mm)	R(h*, 0) (N)	B(h, σ) (N)	B(h, 25) (N)	R(67, 25) (N)
1	0.25	446	65.2	149	292	292	444
1	0.80	597	66.1	269	329	266	543
2	0.25	443	66.0	158	284	322	485
2	0.80	642	65.0	279	356	356	645

Figure 3



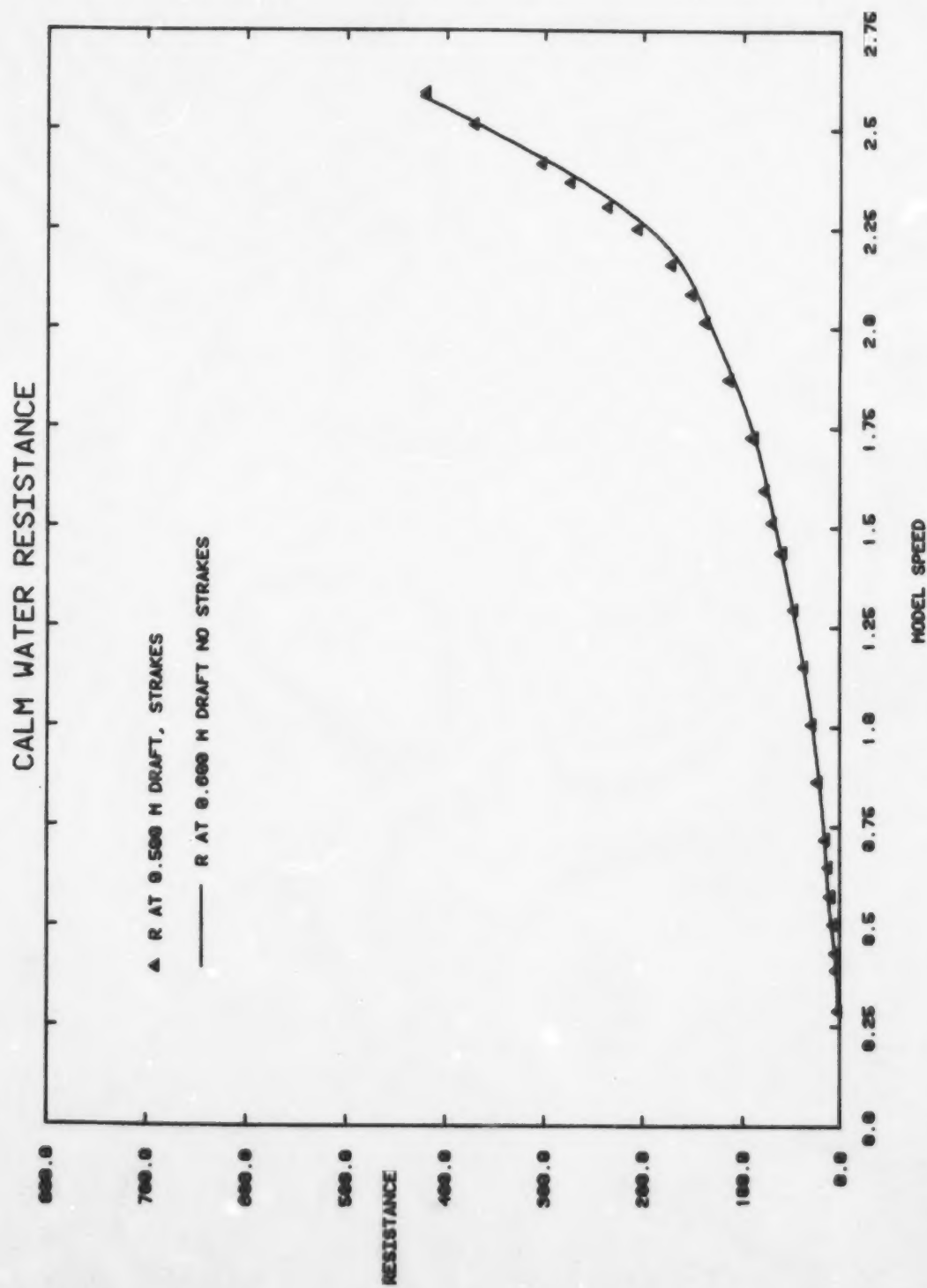
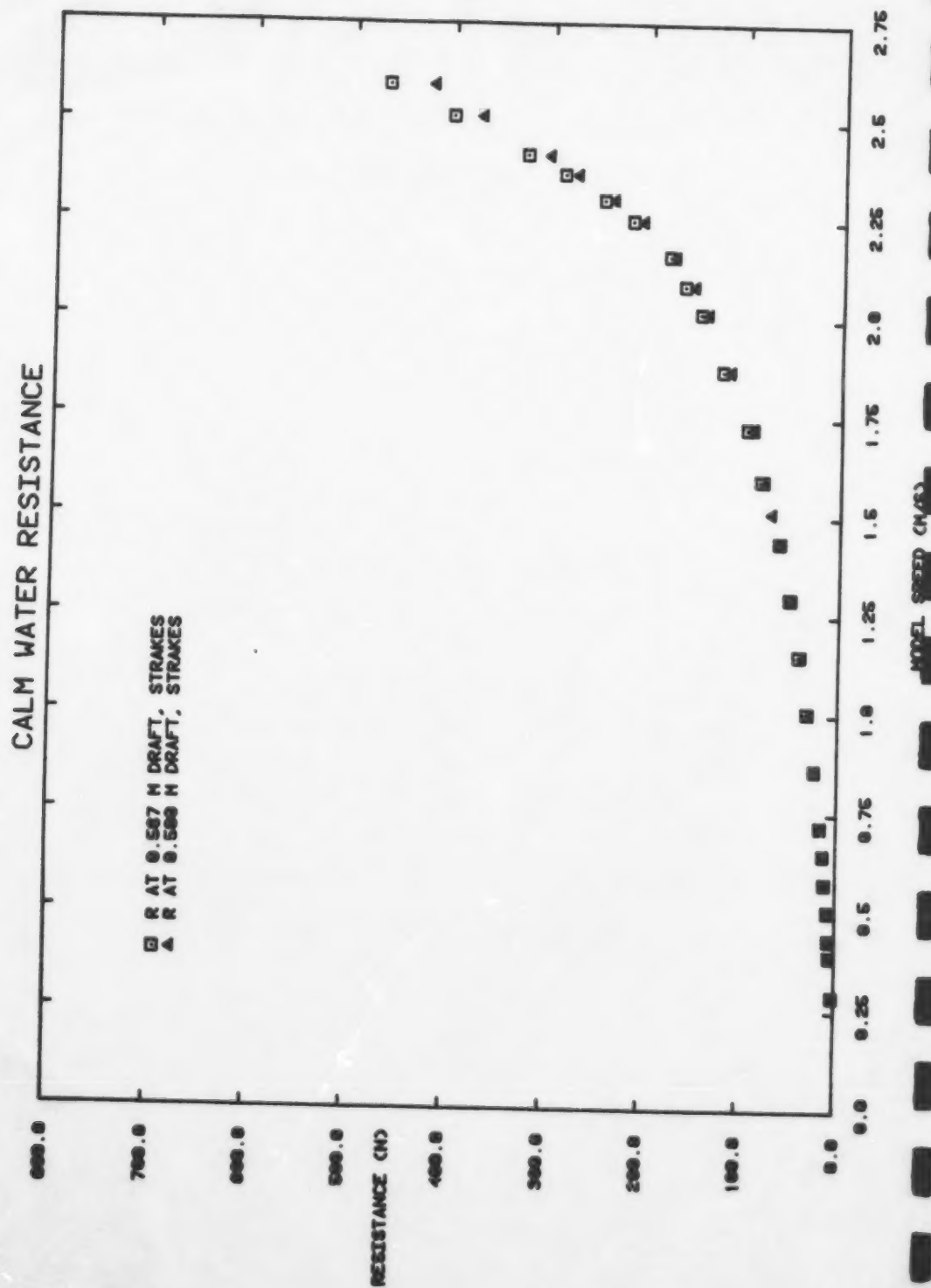
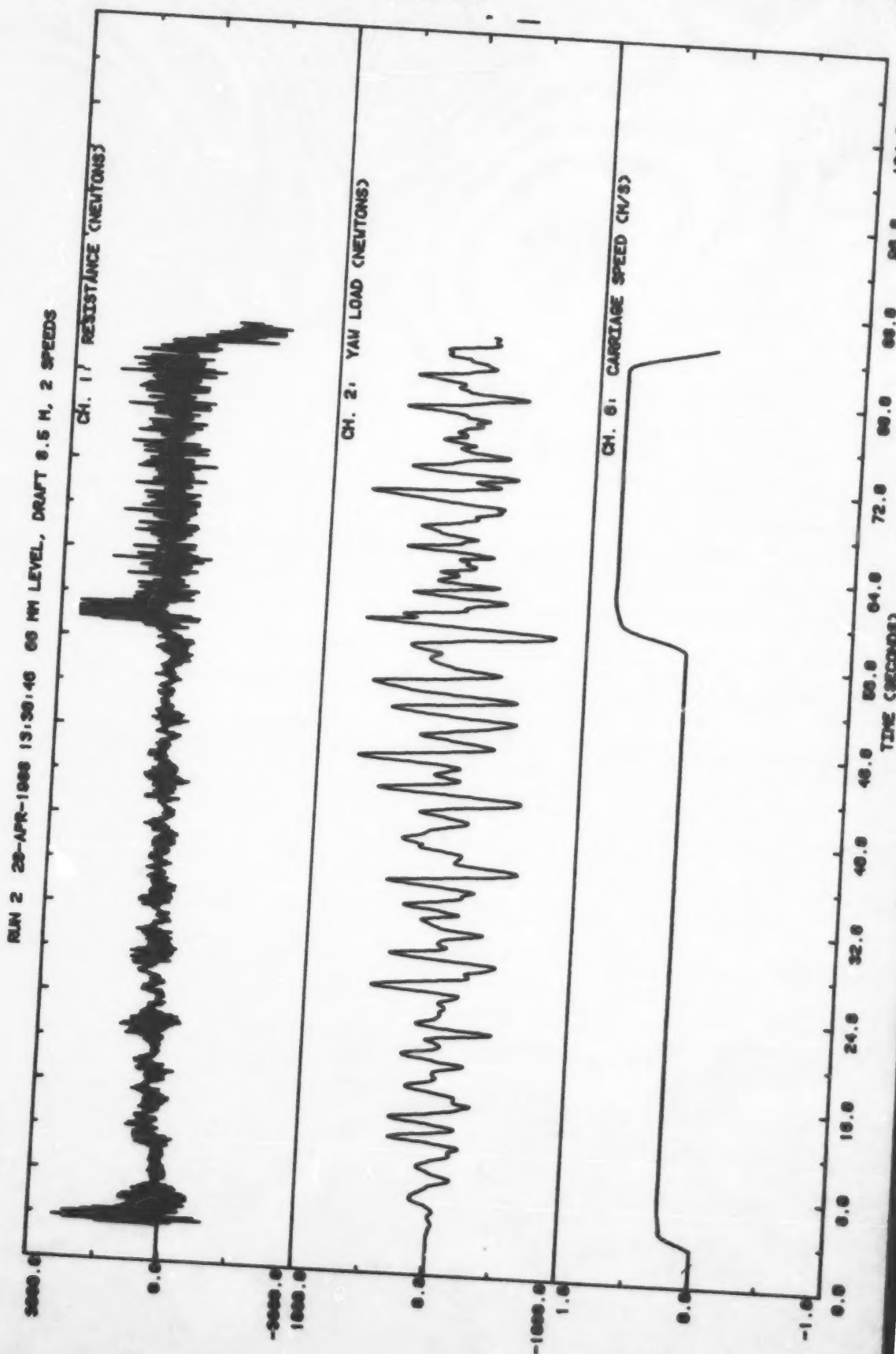
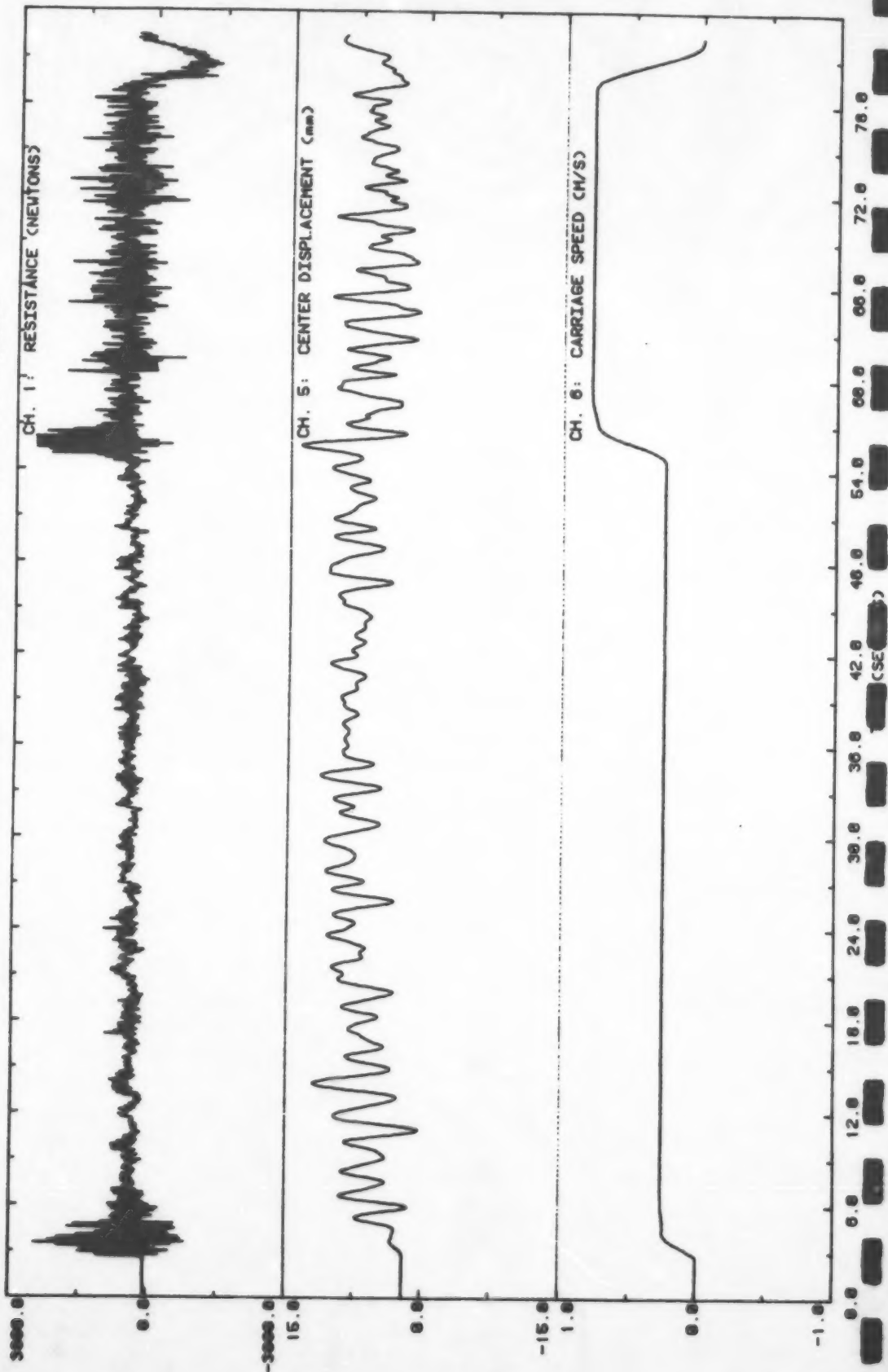


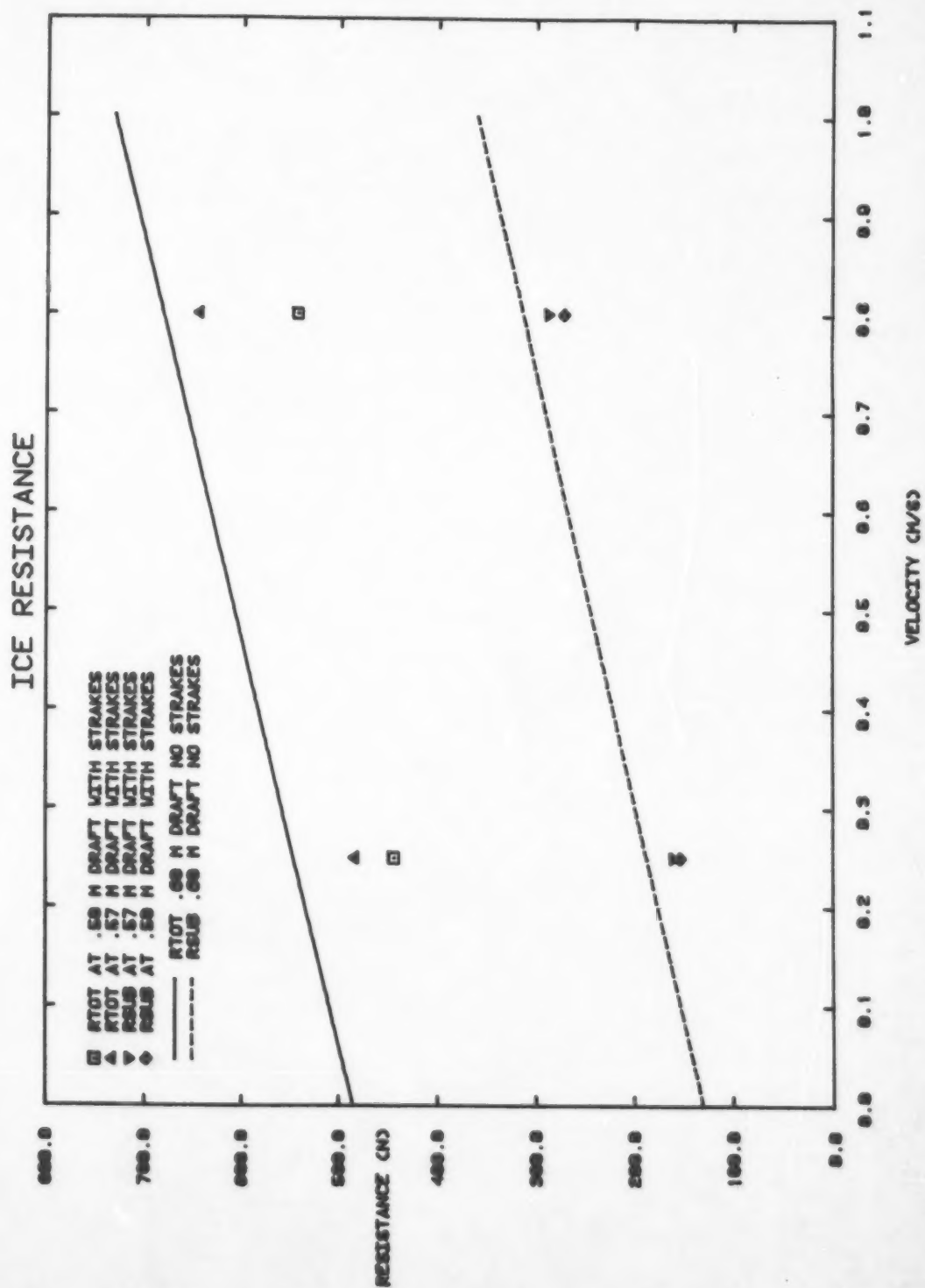
Figure 5





RUN 1 28-APR-1988 12:43:48 LOUIS STRAKES AT 7.5 M DRAFT, 2 SPEEDS





APPENDIX

NRC - INSTITUTE FOR MARINE DYNAMICS

ARCTIC VESSEL RESEARCH SECTION

ICE SHEET SUMMARY

Test Name: CARTER1

Project Number: 88105

Target ice thickness: (mm) 67.0

EG/AD/S: (%) .39/.027/0

Target ice strength: (kPa) 30.0

SEEDING:

Air temp.(max/min) C: -19.0/-14.6
Seeding completed at 2148 18-APR-1988
Seed volume: 1 28.3
Humidity: tank(%) 70
 room(%) 38

Tank water temp. C: 0.32
Seed duration: (min) 30.
Seed water temp.: C 55.0

GROWTH:

Target temp.: C -20.0
Avg temp. at plateau: C -20.0
Avg temp. of freeze cycle C -19.9
Total negative deg. hours 496.0
Avg growth rate: (mm/hr) 2.319

Time to target temp. hrs: 0.5
Duration of plateau hrs: 24.4
Duration of freeze cycle hrs: 24.9
Thickness at end of freeze: (mm) 57.7
Avg growth rate: (mm/fdh) .116

WARM-UP:

Warm-up commenced at 2240 19-APR-1988
Time to tempering temp: (hrs) 4.0
Final ice thickness: (mm) 66.6
Total growth rate: (mm/hr) 2.677

Length of warm-up: (hrs) 14.
Avg tempering temperature: (C) 0.9
Ice growth during warm-up: (mm) 8.9
Total growth rate: (mm/fdh) .134

* thickness at end of freeze was estimated

MRC - INSTITUTE FOR MARINE DYNAMICS

ARCTIC VESSEL RESEARCH SECTION

ICE MECHANICAL PROPERTIES SUMMARY

Test Name: CARTER1

Project Number: 88105

Warm up commenced: 22:40 19-APR-1988

Time	Warm-up hrs	Loc	hi mm	Sf kPa	Lc cm	E MPa	E/Sf	Lc/hi	Klc N/m	Sf/Klc m-.5	Sc/s kPa	Rho1 Mg/m3
0840	9.99	N S	68.3± 63.3±	1.3 n= 3 0.6 n= 3								
0852	10.19	41S	64.1 64.3	40.± 2.7 26.(u/d 66%)								
0856	10.25	41N	66.8 66.0	42.± 1.8 25.(u/d 58%)								
0858	10.29	41N	66.7						5.7	7.3± 1.4		
0904	10.39	41N	66.0							s	52.3± 3.7	
0908	10.45	41S	63.6							s	48.2± 2.9	
0956	11.25	39N	65.8 65.9	37.± 1.5 28.(u/d 77%)								
0959	11.30	39N	66.9						5.0	7.3± 0.9		
1001	11.34	39S	64.3 64.2	35.± 2.3 22.(u/d 61%)								
1007	11.44	39N	65.4							c	131.8±12.8	
1012	11.52	39S	64.6							c	87.3±11.0	
1023	11.70	37S	64.9		66.	73.5	2218	10.2				
1133	12.87	37S	64.6 64.5	24.± 2.6 21.(u/d 86%)								
1137	12.94	37N	66.6 66.5	24.± 1.0 24.(u/d 99%)								
1145	13.07	37S	63.6									.935
1213	13.54	36S	64.7 64.4	21.± 1.3 20.(u/d 97%)								
1216	13.59	36N	67.0						4.1	5.1± 0.5		
1217	13.60	36N	67.0	21.± 0.2								

66.8 17.(u/d 81%)

1224 13.72 N 66.6± 1.0 n=36
S 66.6± 1.5 n=36

1350 15.15 35W 66.5 18.± 1.0
66.8 18.(u/d100%)

1351 15.17 35W 66.6 3.5 5.2± 0.3

1354 15.22 35S 65.1 18.± 1.1

1400 15.32 N 66.1± 1.2 n=34
S 65.2± 1.0 n=34

Run #	Date	Time	Hours from Warm-up	Flexural Strength		
				north	south	mean

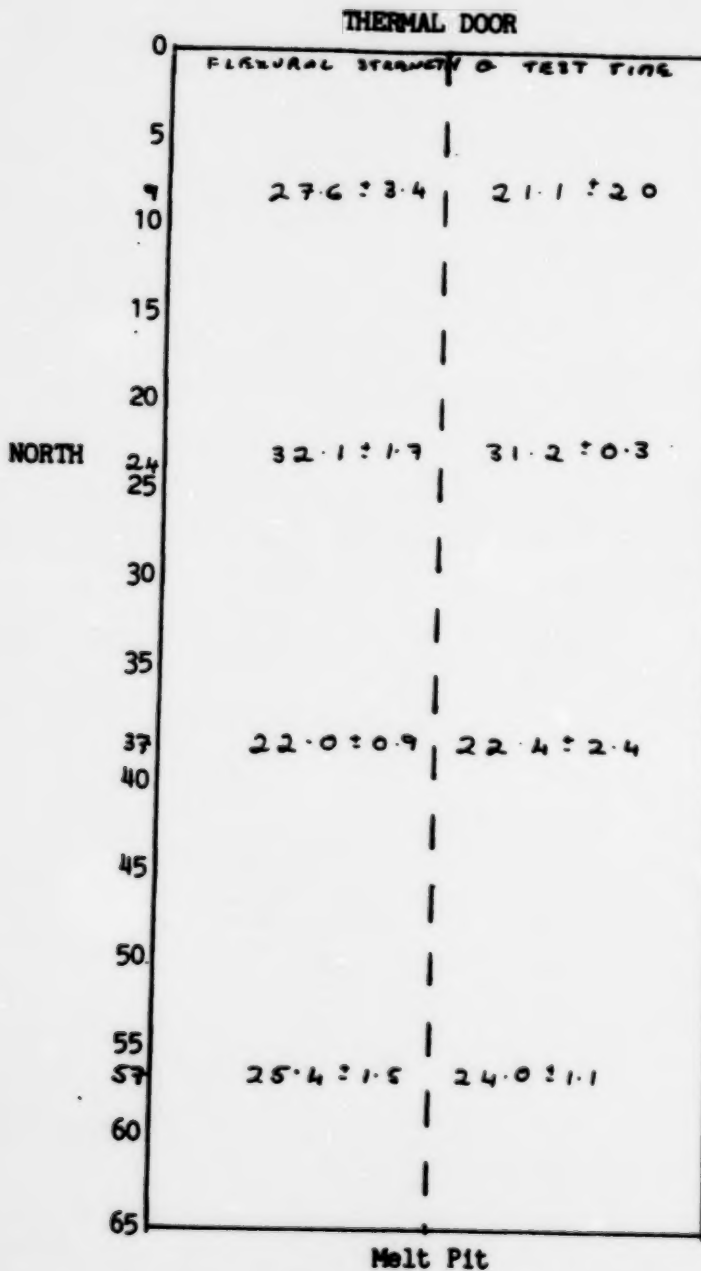
LEVEL ICE 1	04/20/88	1115	12.57	25.2	25.4	25.3
-------------	----------	------	-------	------	------	------

LEVEL ICE 2	04/20/88	1159	13.30	22.1	21.6	21.8
-------------	----------	------	-------	------	------	------

PRESAWN 3	04/20/88	1322	14.69	19.9	19.8	19.8
-----------	----------	------	-------	------	------	------

PRESAWN 4	04/20/88	1406	15.42	17.3	17.4	17.4
-----------	----------	------	-------	------	------	------

NATIONAL RESEARCH COUNCIL
INSTITUTE FOR MARINE DYNAMICS
ICE SHEET PROPERTIES AND LOCATION DIAGRAM



FILE NAME: CARTER 1.

① TEST TIME: 1115 20 APRIL '88

Avg σ_f = 25.0 ± 4.4; n = 5

λ = 67.3 ± 2.3; n = 14

Avg σ_f = 31.6 ± 1.2; n = 6
SOUTH

λ = 65.8 ± 0.6; n = 18

AVERAGE FOR ABOVE LOCATIONS

σ_f = 28.6 ± 4.5; n = 11

λ (2-32n) = 66.5

② TEST TIME: 1159 20 APRIL 1988

Avg σ_f = 22.2 ± 1.7; n = 8

λ = 66.6 ± 0.8; n = 14

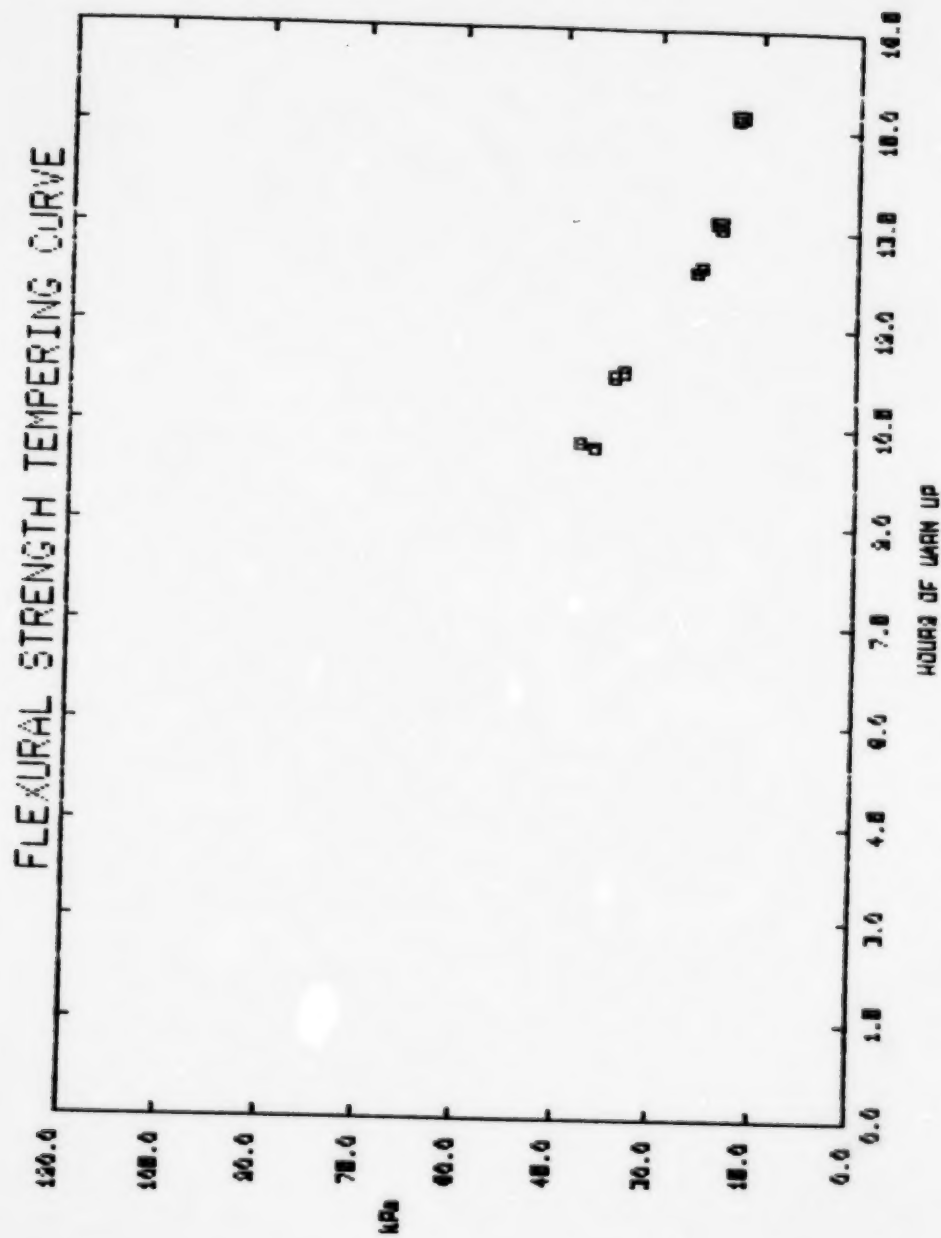
AVERAGE FOR ABOVE LOCATIONS

σ_f = 23.3 ± 2.0; n = 14

λ (34-66) = 66.7

CARTER 1

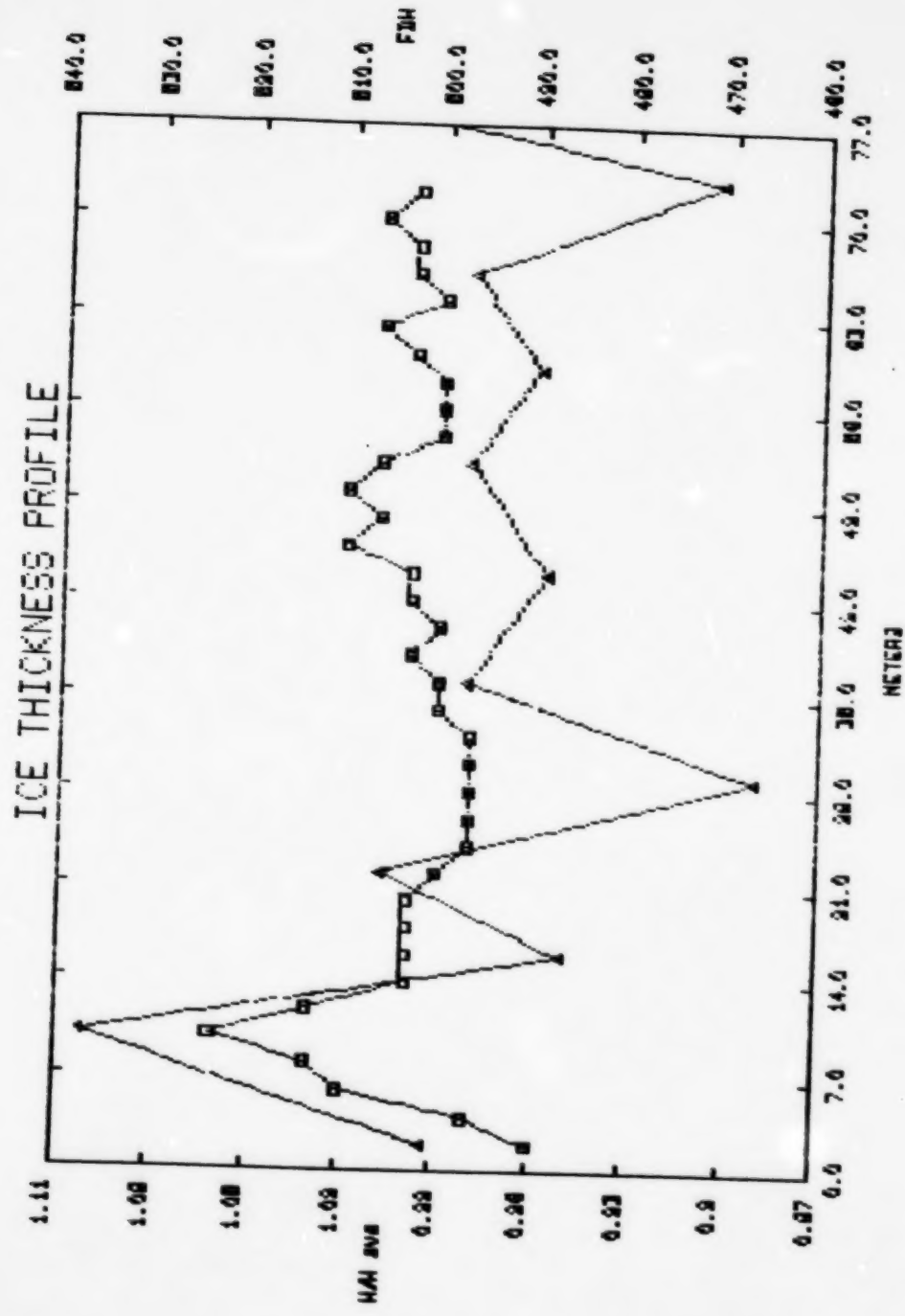
67MM



CARTER 1

CENTER CHANNEL

67MM



APPENDIX "D"

COMPUTER PROGRAM LISTING
AND SAMPLE RUN


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▽ STRAKES; A; B; FST; I; K; M; M1; MD; MFORCE; MFV; MFUEL; MI; MR; MRX; MX; MY; POSTR; RATIO
[1] DATA
[2] MGEO ICEFORCE VEL+0, 110
[3] ST10: 'WHAT IS THE STRAKES SIZE?' ◇ SIZE+0 ◇ +(2*ρ(SIZE, SIZE))ρST10
[4] ST11: 'METRES OR FEET (M OR F)?' ◇ +('FM'=1+0)/ST12, ST13 ◇ +ST11
[5] ST12: SIZE+0.3048*SIZE
[6] ST13: MD+(ρMDATA)ρ(MDATA[1;2]-MDATA[2]), MDATA[ 1 3 4 5]
[7] (SIZE*14)CURVE MD ◇ MC; 1 2] +MC; 2 1]
[8] SAUT: POSTR+(1+ρM)ρ0 ◇ I+1
[9] ST14: POSTR[I]+(ΓMGEO[1]-MC[I;1])[1] ◇ +(ρPOSTR)2[I+1+1)ρST14
[10] A+MGEO[POSTR;3]*180+01 ◇ B+MGEO[POSTR;5]*180+01
[11] RATIO+0.833*0.5+(0.05*A+30)+(0.2*B+30)+(0.25*A*B+900) ◇ X+151 ◇ Y+51ρ1
[12] FST+ΔR2X[POSTR]*RATIO ◇ POSTR+0, POSTR ◇ I+2 ◇ MI+ρ((ρPOSTR), 51)ρX
[13] MR+ρ((ρPOSTR), 51)ρY
[14] ST15: MIC; I]+X ◇ MICK+(POSTR[I-1]+1(POSTR[I]-POSTR[I-1])); I]+POSTR[I]
[15] X+MIC; I] ◇ MRC; I]+Y ◇ MRC; I]+RATIO[I-1] ◇ Y+MRC; I]
[16] +(ρPOSTR)2[I+1+1)ρST15
[17] MRX+ 0 1 +MDX*ρ(ρMDX)ρΔL, 1
[18] MX+ρ((1+ρPOSTR), (ρTHICK))ρTHICK ◇ K+1 ◇ I+2
[19] ST16: MX[K; I]+MRX[52; K]++/2*SIMP*MRC; I-1]*MRX[MIC[51; I-1]); K]
[20] +(ρTHICK)2[K+K+1)ρST16 ◇ K+1 ◇ +(1+ρPOSTR)2[I+1+1)ρST16
[21] MY+MX[1], [2] 0 1 +100*MX+ρ(ρMX)ρMX[2]
[22] 'POSITION OF THE STRAKES FROM MAX. BEAM' ◇ M1+ρ(2, 1+ρM)ρ(1+ρM), MC; 1]
[23] 'STRAKE DISTANCE (M)' ◇ ' ' ◇ 'I4, F13.2' DFMT M1 ◇ ' ' ◇ ' '
[24] 'INFLUENCE OF THE NUMBER OF STRAKES ON THE ICE RESISTANCE (KN)'
[25] ' AT CREEPING SPEED'
[26] ' ICE NUMBER OF STRAKES'
[27] 'THICKNESS 0 1 2 3 4' ◇ ' '
[28] 'F9.4, F12.2, 4F10.2' DFMT MX ◇ ' ' ◇ ' '
[29] 'INFLUENCE OF THE NUMBER OF STRAKES ON THE ICE RESISTANCE (°/°)'
[30] ' AT CREEPING SPEED'
[31] ' ICE NUMBER OF STRAKES'
[32] 'THICKNESS 0 1 2 3 4' ◇ ' '
[33] 'F9.4, F12.2, 4F10.2' DFMT MY ◇ ' ' ◇ ' '
[34] 'INFLUENCE OF THE SHIP SPEED (M/S) ON THE ICE RESISTANCE (°/°)'
[35] 'SHIP ICE THICKNESSES (M)'
[36] ('SPEED (M/S)', (11*ρTHICK)ρ'F11.4' DFMT THICK) ◇ ' '
[37] MFV+MFUEL[1], [2] 0 1 +MFUEL*100 ◇ 'F11.4' DFMT MFV

```

STRAKES
ICE COVER CHARACTERISTICS
SAME AS PREVIOUS RUN OR NEW?
ANSWER S OR N

N
ENTER ICE FLEXURAL STRENGTH
:

450
WHAT UNIT, KPA OR PSI?
ANSWER K OR P

K
DO YOU KNOW THE RATIO 'E/SIGMA' (YES OR NO)?
N
ENTER HULL/ICE FRICTION COEFFICIENT
:

0.1
ENTER ICE THICKNESSES (UP TO 5 VALUES)
:

0.75 1.00 1.25 1.50
WHAT UNIT, METRES OR FEET? (M OR F):
M

VESSEL'S PRINCIPAL PARTICULARS
SAME AS PREVIOUS RUN OR NEW?
ANSWER S OR N

N
ENTER SHIP'S NAME
LOUIS S. ST.LAURENT
ENTER LENGTH (B.P)
:

101.83
WHAT UNIT, METRES OR FEET? (M OR F)
M

ENTER DRAUGHT
:

28
WHAT UNIT, METRES OR FEET? (M OR F)
F

ENTER DISPLACEMENT
:

15000
WHAT UNIT? CUBIC METRES, METRIC, LONG OR SHORT TONS?
ANSWER C, M, L, OR S

C
ARE GEOMETRICAL PARAMETERS KNOWN ALONG FOREBODY WATERLINE?
PLEASE ANSWER YES OR NO

Y

ARE THE GEOMETRICAL DATA ALREADY STORED? (ENTER YES OR NO)

Y

ENTER THE NAME ASSIGNED TO YOUR GEOMETRICAL DATA (EX. MLOUIS)

:

MLOUIS

PLEASE CHECK YOUR DATA

DISTANCE FORWARD MAX.BEAM (X)	HALF BREADTH (Y)	WATERLINE SPREAD ANGLE ALPHA	SECTION FLARE ANGLE BETA	BUTTOCK ANGLE GAMMA
0.00	39.80	0.00	4.50	0.00
16.70	39.75	0.20	4.50	2.50
33.40	39.63	1.50	4.50	18.40
50.10	38.99	3.20	5.40	30.60
66.80	37.83	5.20	7.10	36.20
83.50	35.76	9.00	10.60	40.80
100.20	32.37	13.30	15.40	42.30
116.90	27.40	19.60	22.00	42.30
133.60	20.15	26.00	31.20	41.30
141.95	15.76	29.80	36.00	40.30
150.30	10.50	33.20	39.50	38.60
158.65	4.50	36.10	42.00	36.50
164.60	0.23	38.00	43.00	32.00

ANY CORRECTIONS? (ANSWER YES OR NO)

N

ARE X AND Y EXPRESSED IN METRES OR FEET?

PLEASE ENTER M OR F

F

I'M PRESENTLY DETERMINING THE GEOMETRICAL PARAMETERS
ALONG THE HULL-ICE INTERFACE

I'M PRESENTLY DETERMINING THE ICE FORCES ACTING
ALONG THE HULL/ICE INTERFACE

WHAT IS THE STRAKES SIZE?

:

0.3

METRES OR FEET (M OR F)?

M

POSITION OF THE STRAKES FROM MAX. BEAM
STRAKE DISTANCE (M)

1	15.86
2	20.35
3	23.50
4	25.29

INFLUENCE OF THE NUMBER OF STRAKES ON THE ICE RESISTANCE (KN)
AT CREEPING SPEED

ICE THICKNESS	NUMBER OF STRAKES				
	0	1	2	3	4
0.7500	1354.90	1067.75	1009.42	981.03	969.51
1.0000	1984.10	1571.34	1487.39	1446.23	1429.46
1.2500	2675.15	2128.15	2016.73	1961.73	1939.25
1.5000	3422.54	2733.96	2593.49	2523.71	2495.09

INFLUENCE OF THE NUMBER OF STRAKES ON THE ICE RESISTANCE (°/°)
AT CREEPING SPEED

ICE THICKNESS	NUMBER OF STRAKES				
	0	1	2	3	4
0.7500	100.00	78.81	74.50	72.41	71.56
1.0000	100.00	79.20	74.97	72.89	72.05
1.2500	100.00	79.55	75.39	73.33	72.49
1.5000	100.00	79.88	75.78	73.74	72.90

INFLUENCE OF THE SHIP SPEED (M/S) ON THE ICE RESISTANCE (°/°)
SHIP ICE THICKNESSES (M)

SHIP SPEED (M/S)	0.7500	1.0000	1.2500	1.5000
0.0000	100.0000	100.0000	100.0000	100.0000
1.0000	107.2186	106.2799	105.6346	105.1556
2.0000	126.4251	123.2140	120.9738	119.2931
3.0000	153.1746	147.1694	142.9265	139.7118
4.0000	184.2098	175.2906	168.9338	164.0834
5.0000	217.7055	205.8777	197.3996	190.8999
6.0000	252.6852	237.9817	227.4025	219.2660
7.0000	288.6097	271.0643	258.4076	248.6520
8.0000	325.1661	304.8068	290.0939	278.7355
9.0000	362.1631	339.0124	322.2604	309.3130
10.0000	399.4782	373.5539	354.7765	340.2514